THE SCIENCE READERS

# The BOOK of ELECTRICITY

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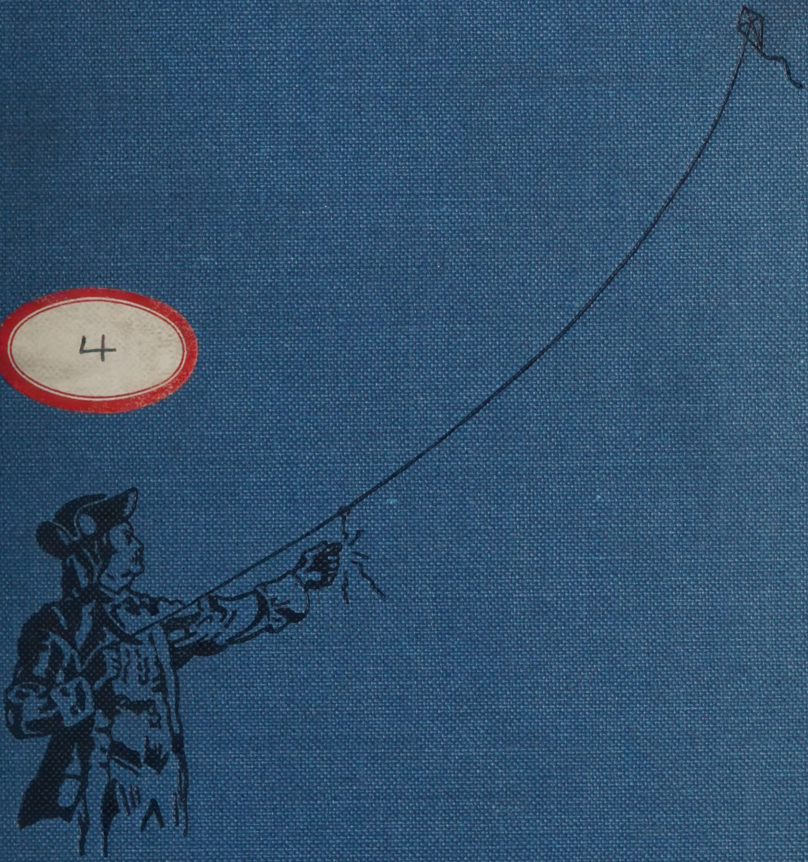

BERTHA MORRIS PARKER

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The Science Readers

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# THE BOOK OF ELECTRICITY

BY

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# PREFACE

The Book of Electricity is designed to serve as informational silent-reading material for children of the sixth, seventh, and eighth grades. It is one of a series of Science Readers planned to meet the need for silent-reading material which presents detailed, well-organized information concerning scientific phenomena. The author believes that it will prove useful not only in science classes, but also as content material for use in silent-reading classes in schools which do not include science courses in their curricula.

Devices operated by electricity now make up so conspicuous an element of our environment that every child has a right to be taught something of the ways in which electricity has been harnessed to help us. If the curriculum provides for no science work, children should at least have their experiences with electrical phenomena rationalized through the medium of silent reading.

A glance at the Table of Contents shows that three types of material are included in the text: explanations of electrical phenomena and discussions of the ways in which electricity is generated and used; stories of invention; and directions for ex-

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periments and construction work. The directions for experiments do not make the book a laboratory manual in any sense. Directions for experiments are given only in case the materials to be used are so easily obtainable that the children may be able to get the materials and perform the experiments for themselves. No attempt is made to give directions for demonstration experiments which should be performed if units dealing with electricity form a part of a science course.

Some of the material is designed as intensive, some as extensive reading material.

If the book is used as silent-reading material apart from a science course, the author considers it advisable to read the chapters in the order in which they are included. In case the material is used in a reading class, the chapters which give directions for experiments or for construction work should be regarded as optional. These chapters may be omitted without spoiling the continuity of the text.

For use with a science class, the text material, as the Table of Contents shows, has been organized into eight units. In teaching a science class, the subject matter should be handled unit by unit, not chapter by chapter. The reading material will serve to explain phenomena observed, to check conclusions arrived at by experimentation and class discussion, to answer questions raised by the class, to give directions for simple experiments, to broaden the children's experiences within this field of science, and to give some idea of scientific method through accounts of the work done by famous workers in this field.

The pictures in the book have been so chosen and used as to be an important and integral part of the text.

The book is the outgrowth of the author's several years of experience in teaching units about electricity as a part of the science course in the University Elementary School of the University of Chicago. The material has been used for the most part with sixth-grade classes.

The author expresses her gratitude to Professor Timbie, of the Massachusetts Institute of Technology, who examined the entire manuscript critically.

Bertha Morris Parker

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# THE BOOK OF ELECTRICITY

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## I. ELECTRICITY: OUR NEW SLAVE

A MOTORMAN moves a lever, and a trolley car goes down the street. A little button on the wall is pushed, and a room is flooded with light. The telegrapher taps his key, and a message is sent tens or hundreds or even thousands of miles. A switch is closed, and a huge magnet picks up a ten-ton load of iron. All this looks like magic. A thousand years ago, most people would certainly have called it magic. Even a hundred years ago, most people would have been utterly amazed and would have wondered how such things could possibly be done. We see such things every day and do not wonder at them at all. We know, when we see such happenings, that our new slave, electricity, is being put to work.

People have known of electricity for at least twenty-five hundred years, but, until about a hundred years ago, no one had ever been able to put it to work. In 1820, just a little more than a hundred years ago, a book was written about electricity in which the author said that everything that could be done with electricity had been done. And at that time it was used for nothing except experiments in science laboratories! From then on the story of electricity is the story of one invention after another. Way after way has been found of putting electricity to work.

How many of the following things do you have in your home?

Electric grill
Electric laundry iron
Electric mangle
Electric lights
Electric percolator
Electric oven
Electric doorbell
Electric foodchopper
Electric polisher
Electric fan
Electric washing machine
Electric phonograph
Electric refrigerator
Electric burglar alarm
Telephone
Radio
Electric chafing dish
Electric curling iron
Electric vacuum cleaner
Electric toaster
Electric stove
Electric sewing machine
Electric water heater
Electric coffee grinder
Electric heating pad
Electric waffle iron
Electric dish-washing machine
Electric player piano
Electric medical coil
Electric vibrator
Electric mixer
Electric air heater

Although most of us do not use all these devices for making electricity do useful things for us, most of us use some of them. How hard it would be to do without them all! But, a hundred years ago, not a single one of them could be bought; they had not yet been invented.

Imagine for a moment that it suddenly became

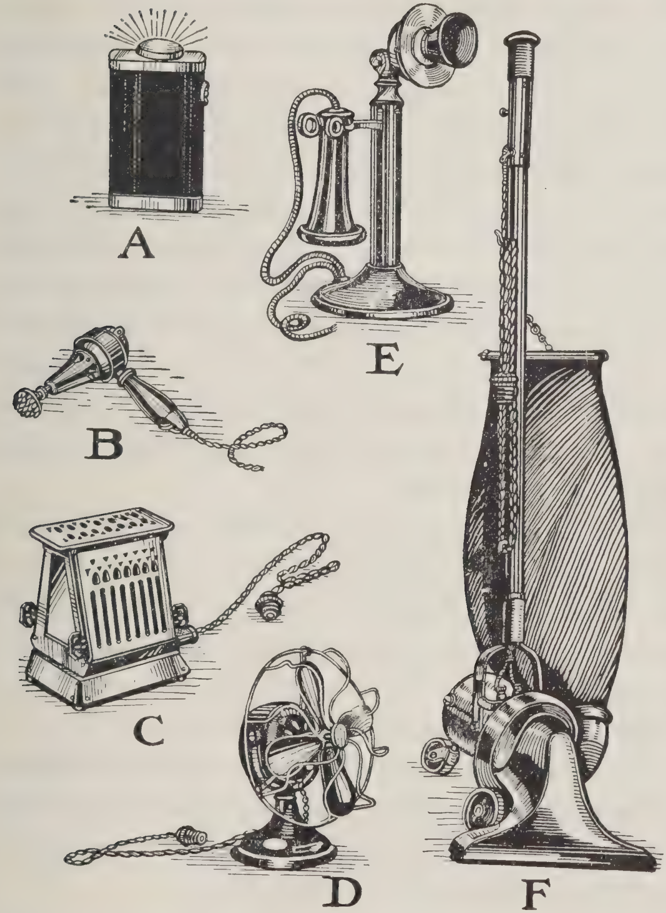


FIG. 1. SOME WAYS OF USING ELECTRICITY

***A***, flashlight — *B*, vibrator — *C*, toaster — *D*, fan — *E*, telephone — *F*, vacuum cleaner impossible to get a current of electricity in any way. What would happen in a city like Chicago? Street cars could not run. Electric trains would stop. There would be no electric sparks to make the gasoline in automobile engines explode, and gas cars would stop, too. Of course electric cars could not run. Very many people in a big city depend upon electricity to take them to their work. With the supply of electricity shut off, they would have to walk unless they could get horses or bicycles, or could travel on trains pulled by steam engines. With no electric elevators running, those people who had offices on the upper floors of skyscrapers would be unfortunate indeed.

All the moving-picture theaters would have to close. For lights, people would have to go back to gas lights or oil lamps or candles. At night the streets would look queer without their bright electric signs.

Electromagnets would drop their loads.

No matter how many of the electric devices shown in Figure 1 or listed on page 2 people had in their homes, these devices would all be useless with no current of electricity to operate them.

Work would have to stop in factories where electricity is used to plate cheaper metals with silver or nickel or copper. Factories in which the machines are run by electricity would be idle, too.

Doctors could not use their X-ray machines or their electric needles or their quartz lights. All their expensive electrical equipment would be valueless.

Telegraph, telephone, cable, and radio messages would be impossible. The newspapers for a time would have almost no news to print.

Imagining such a state of affairs may help you realize how much we have come to depend upon this new slave of ours.

# FRICTIONAL ELECTRICITY

## II. ELECTRICAL CHARGES

If, on a cold, clear day, you rub a rod of hard rubber with a piece of woolen cloth, you can then pick up bits of paper with the rod. Your fountain pen will do as well as a hard rubber rod unless your fountain pen case happens to be a metal one. The rod and the fountain pen pick up the paper because they are charged with electricity. A glass rod which has been rubbed with a silk pad will pick up bits of paper just as the rubber rod does. Bits of straw or bits of cork might be used instead of bits of paper. As such experiments show, an object charged with electricity will attract bits of light-weight materials.

Rubbing two kinds of materials together is the oldest way of getting electricity. For more than twenty centuries it was the only way known.

Electrical charges produced by rubbing two materials together are spoken of as "frictional" electricity. If you know that friction means rubbing, you understand why these charges are called frictional electricity. Sometimes such charges are spoken of as "static" electricity instead.

There are many experiments which you can perform with frictional electricity. You will get the best results if you do these experiments on a cold, clear day. When there is much moisture in the air, as there is very likely to be on warm days, the electricity escapes rapidly through the air. It seems then that no electric charge is being produced.

Most of us have had experiences with frictional electricity whether we have tried to experiment with it or not. Perhaps, when you have been writing, you have found that, whenever you lifted your arm, the paper on which you were writing would stick to your sleeve. This is because your sleeve rubbed the paper as you wrote. Perhaps you have stroked a cat's back and have seen little electric sparks. Probably you have had the experience of getting a shock after you shuffled your feet across a heavy rug and then held your finger near a radiator or some other piece of metal. You may have heard a faint crackling noise as the electricity left your body. You may have held your finger near another person's hand or face, after you shuffled across a heavy rug or carpet, so that he would feel a shock as the electricity jumped from your body to his.

Some of the guests in a big hotel in Chicago complained that they could not walk downstairs without getting a series of electric shocks. The carpet on the stairway was very thick, and the railing along the stairway was metal. Do you see why they got shocks every few steps? There were no complaints of this kind during the summer. Do you understand why there were not?

A foreign maid objected to making the beds in a certain home. She said that it was just as if something bit her when she touched the brass rod of the bed after she had smoothed the covers. Of course you understand that the "bite" was a slight electric shock.

Two objects charged with electricity in the same way repel each other. This means that they push each other away if possible. Have you noticed that, after you have picked up bits of paper with a glass or rubber rod, the little pieces soon jump away from the rod? The bits of paper, after they touch the rod, become charged with electricity. Then the rod chases them away. You should understand now why your hair sometimes "stands on end" on a cold day. When you comb it, every hair becomes charged with frictional electricity. Each hair, therefore, gets as far away from its neighbors as it can.

You may have had experiences which showed you that objects charged with electricity do not always repel each other. You may have found, for example, that a bit of paper which had become charged and had jumped away from a glass rod was attracted by a rubber rod which had been rubbed with wool. Scientists had many such experiences before they found out the reason for them. They then found that not all charges of electricity are alike. The kind of charge on a rubber rod after it has been rubbed with wool or fur is called a " negative charge." The kind of charge on a glass rod after it has been rubbed with silk is called a "positive charge." Any charge like the charge on the rubber rod is a negative charge, and any charge like the charge on the glass rod is a positive charge. If two things each have a positive charge, they repel each other. If two things each have a negative charge, they repel each other. But, if one has a negative charge and one has a positive charge, they attract each other.

An electroscope such as the one shown in Figure 2 is a device for finding out whether or not an object is charged with electricity. The most important part of the electroscope is the folded strip of gold foil. If an object charged with electricity is held near the electroscope, the piece of gold foil becomes charged, and the two ends move away from each other. Figure 3 shows a homemade electroscope. In it aluminum foil or very light-weight tinfoil is used instead of gold foil.

So far as we know, the first person who ever experimented with frictional electricity was a Greek philosopher named Thales. Thales was one of the "seven wise men of Greece." About six hundred years before the time of Christ, Thales discovered

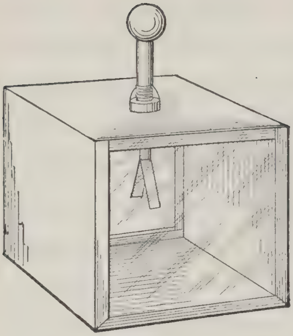


Fig. 2. An Electroscope

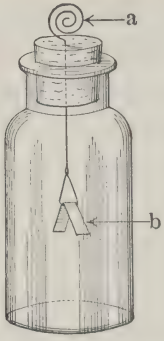


Fig. 3. A Homemade Electroscope
*a*, copper wire — *b*, aluminum foil

that a piece of amber which he had rubbed with a piece of woolen goods would pick up bits of straw or dry leaf. Probably he thought that it was fun to do these experiments, but he certainly didn't think that they were very important. He didn't know why the amber picked up the bits of leaf and straw, and, so far as we know, he didn't try very hard to find out. How surprised he would have been if he could have known that he was experimenting with electricity, which, more than two thousand years later, was to be harnessed and put to work.

Other Greek scientists performed the experiments Thales had done. Roman scientists learned of them from the Greeks; but neither the Greeks nor the Romans understood what happened in these experiments.

Twenty-two hundred years after the time of

Thales, Dr. William Gilbert, an Englishman, repeated the experiments Thales had performed. He did others besides. He soon found that glass or sealing wax or jet could be used in place of amber. Here, he decided, was something worth investigating. He must find out more about this new source of energy. Dr. Gilbert did not succeed in finding out a great deal about it, but he did give it a name. The Greek word for amber is "electron." Dr. Gilbert called the new source of energy "electric" because the first experiments were done with amber. Our word "electricity" really comes, then, from the Greek word which means amber.

Soon after the time of Gilbert, the great German scientist, Otto von Guericke, invented an electric machine. By using his machine, he could rub two materials together so rapidly that good-sized electric sparks could be produced.

From that time on many scientists studied electricity. Better and better electric machines were made. Figure 4 shows you one of these electric machines. An electric condenser, the Leyden jar, was invented. With it electricity could be stored until a heavy charge was accumulated. Large sparks could then be produced. As you see, two Leyden jars form a part of the machine shown in Figure 4. Hundreds of interesting experiments with electricity were performed. Many interesting ex-

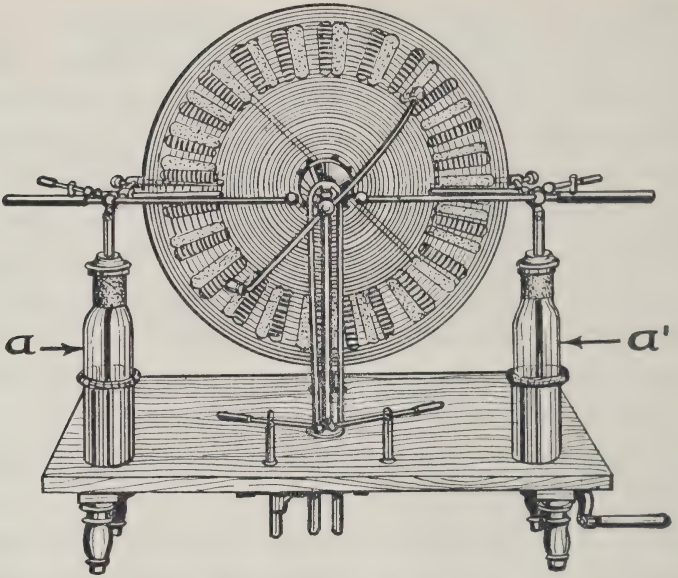


Fig. 4. An Electric Machine
*a, a'*, Leyden jars

periments are still done with these electric machines. If no one, however, had ever found any other ways of generating electricity, probably electricity wouldn't be very much more important to us now than it was to people in the time of Thales of Greece.

## III. FUN WITH FRICTIONAL ELECTRICITY

The following experiments are easy to perform. If you do not understand the results, read again the chapter about electrical charges. The results of all these experiments are explained there.

1. Comb your hair with a rubber or celluloid comb. Try to pick up bits of paper with the comb.

2. Hold a big sheet of tissue paper against a smooth wall. A slate blackboard is an excellent wall for this experiment. Rub the paper with a piece of silk cloth. Try folding the paper with one hand while it is on the wall. You should be able to fold it several times without making it fall from the wall. Smooth the paper out on the wall again. Then pull it away from the wall. If you do this experiment at night, you may see tiny sparks as you pull the paper away from the wall.

3. Put a piece of paper flat on a smooth table and then rub the paper with your finger nails. You will find that it is not easy to lift the paper from the table.

4. Take a piece of tissue paper about six inches square. Cut a fringe along one edge of the paper. Lay the paper on a table and rub it with a silk pad. Then lift the paper from the table. The strips of the fringe will stand out from one another.

5. A little ball of pith is very useful in doing experiments with frictional electricity. Pith is a material which comes from the inside of certain plant stems. In this experiment, if you cannot get pith, a tiny bit of cork will do. Fasten the ball of pith to the end of a silk thread. Then hang the ball up by means of the silk thread. Rub a glass rod with a

pad of silk. Hold it near the pith ball. The rod will attract the pith ball; but very soon after the pith ball touches the rod it will become charged with electricity and jump away. If the charge on your rod is a strong one, you will find it fun to try to touch the pith ball with the rod.

6. Hold your finger near the charged pith ball. The ball will come to it. As soon as the ball touches your finger, the charge of electricity will escape into your body. Then the charged rod will once more attract the ball. If you hold your finger about an inch from the end of the rod, you should be able to keep the ball going back and forth between them for some time.

7. Try Experiments 5 and 6 with a rubber rod which has been charged by rubbing it with a pad of wool.

8. Put two books which are each about an inch and a half thick on a table and about six inches apart. Cut out a row of tissue paper dolls about an inch tall. Stand them on the table between the books. Then place a plate of glass above the paper dolls so that the ends of the plate of glass rest on the books. Rub the glass with a silk pad. The paper dolls should dance up and down. They jump up to the glass and become charged. Then they jump down. As soon as their charges escape, they jump up once more.

9. A tiny bit of aluminum foil is needed for this experiment. Rub a glass rod with silk. Pick up the piece of aluminum foil with the rod. As soon as the aluminum foil jumps away from the rod, chase it about the room with the charged rod. Try not to let the foil touch any object.

10. After you have charged a glass rod by rubbing it with silk, hold it near a pith ball. The pith ball, of course, will jump away as soon as it is charged. Then charge a rubber rod by rubbing it with wool or fur. Hold it near the pith ball. You might expect that the rubber rod would chase the pith ball away because they are both charged with electricity, but it doesn't. The pith ball comes to the rubber rod.

## IV. FRANKLIN'S FAMOUS EXPERIMENT

What is lightning? If you have read any Greek myths you probably remember that, according to these myths, lightning was a firebrand hurled to earth by one of the gods. Norse myths explained lightning in the same way. The Dakota Indians believed that lightning was a spark caused by the rushing of the "cloudbird" across the sky, just as sparks were caused when a buffalo scampered over a stony plain. They thought that thunder was the noise made by the flapping of the cloudbird's wings.

People gradually outgrew such ideas as these. However, after people had decided that these old explanations were all wrong, they were at a loss to find a satisfactory explanation. Two hundred years ago, most scientists believed that lightning was caused by the rapid burning of some kind of gas in the clouds. Benjamin Franklin was the first person to find out what lightning really is.

In 1746, while he was in Boston, Franklin saw some experiments which interested him very much. They were experiments with frictional electricity. Franklin wished to do some of the experiments which he had seen. He soon obtained the apparatus he needed. He had an electric machine with which he could produce long sparks of electricity. As he performed experiments with this machine, it occurred to him that these sparks of electricity were like lightning in many ways. Could it be that lightning was only a huge electric spark?

The more carefully Franklin watched the electric sparks which he got from his machine, the more nearly convinced he was that lightning and electricity were one and the same thing. The thunder, he reasoned, might correspond to the crackling noise caused by a spark from his machine. At length he published a list of the ways in which lightning and an electric spark seemed to him to be alike.

Of course Franklin knew that, if lightning was a spark of electricity, it was a tremendously larger spark than any spark he could get from his machine.

"But why shouldn't it be larger?" Franklin argued. "If I can get a spark two inches long from this little electric machine, why shouldn't the spark from a ten-thousand acre cloud be very large?" And of course it was not to be wondered at that the noise made by a big spark should be louder than that made by a little spark.

Many scientists thought that Franklin was right in thinking that lightning was a huge electric spark; but Franklin was not satisfied until he could prove that he was right. He planned an experiment to test his explanation. If lightning is electricity, then clouds must be charged with electricity; and, if clouds are charged with electricity, it should be possible to get electricity from the clouds. He decided to try to do so.

To get electricity from a cloud, he thought at first that he would have to build a tower with a steeple high enough to reach up to the clouds. To raise money for this tower, he and some of his friends gave lectures about electricity and performed electrical experiments for their audiences.

While Franklin was carrying on this work, two French scientists succeeded in getting sparks from the lower ends of tall pointed rods during a thunderstorm. This seemed to show that lightning was electricity; but Franklin was not yet satisfied. The rods the two Frenchmen used were less than a hundred feet tall. They were not nearly tall enough to reach to the clouds. Perhaps they had been charged in some other way. However, this experiment did suggest to Franklin that there might be an easier way of getting electricity from the clouds than by building a tall tower.

Soon the idea of using a kite occurred to him. To carry out his new plan, he made a kite of silk and put a small piece of wire at the top. To this kite he tied a string made of hemp. At the lower end of the string he fastened a metal key. He also tied a silk ribbon to the end of the string. If clouds were charged with electricity, electricity from the clouds would come down the string, and he would be able to draw sparks from the key. Since electricity does not travel through silk easily, the electricity would not flow through his body into the ground if he held the kite by the ribbon.

He eagerly awaited an opportunity to try out his apparatus. When he saw a thunderstorm approaching he sent up the kite. The first cloud passed. Nothing happened. The second cloud approached. Soon Franklin noticed that the fibers of the hempen string were repelling each other just as they would if they were charged with electricity. He held his knuckle near the key, and a small spark jumped from the key to his hand. It began to rain, and the cord got wet. Franklin was then able to get much longer

*Ewing Galloway, N.Y.*

Fig. 5. A Flash of Lightning

sparks from the key. This showed that the cloud was charged with electricity. Lightning must be, therefore, a huge spark of electricity.

As a result of this experiment of Franklin's and of many later experiments, scientists have been able to work out a full explanation of lightning and thunder. When tiny particles of water are carried upward from the surface of the earth, they rub against the particles of the air through which they pass, and become charged with electricity. When millions of these tiny droplets form a cloud, the cloud is charged with electricity. As more and more droplets are added to the cloud, it is likely to become overcharged. Then an electric spark jumps from the cloud to another cloud which has an opposite charge, or to the ground. This electric discharge sets up sudden light waves, and we see a flash of light. Figure 5 shows a magnificent flash of lightning. As such an electric spark tears its way through the air, some of the air is suddenly pushed aside. This air immediately rushes back again. This sudden motion of the air produces the noise we call thunder.

Franklin's experiment attracted world-wide attention. Perhaps the most remarkable feature of it was that Franklin was not killed. Less than a year later another scientist was killed while trying to repeat this experiment in St. Petersburg, Russia. Franklin's experiment was so much talked about that many people who never before had heard of electricity became interested in it. Some people even thought that Franklin discovered electricity. Of course you know that he didn't; he merely found the answer to the question, What is lightning?

# ELECTRIC CIRCUITS

## V. GETTING CURRENTS OF ELECTRICITY

You can get a charge of electricity by rubbing a rubber rod with fur, but you can't ring an electric doorbell with the charged rubber rod. You can get electric sparks from a machine like the one shown in Figure 4 (page 12), but you can't run a trolley car with these electric sparks. You can't plate a spoon with silver by means of a charge of frictional electricity. For ringing doorbells and running trolley cars and plating spoons with silver, a steady flow of electricity is needed. Such a steady flow of electricity is called an electric current.

Electric currents are needed not only for doorbells and trolley cars and for electroplating, but also for electric lights, electric heating devices, electric motors, and for sending messages by electricity. Since steadily flowing currents are needed for practically all of our electric devices, these devices were not invented and used until after ways were found of getting currents of electricity. There are now two common ways of getting such electric currents: using cells, and using generators.

If you have an electric flashlight you probably know that, hidden inside the case, there is a cell to furnish the needed electric current. There may be

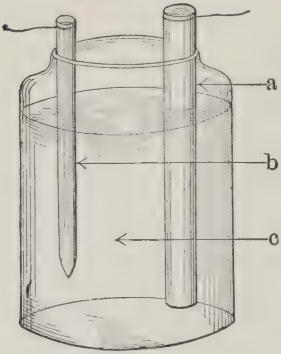


Fig. 6. A Bichromate Cell
*a*, carbon rod — *b*, zinc rod — *c*, solution made of water, sulphuric acid, and potassium bichromate

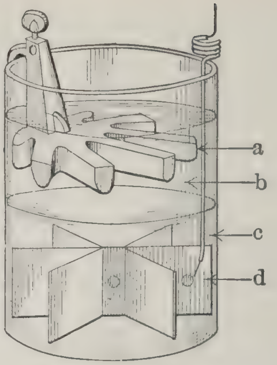


Fig. 7. A Gravity Cell
*a*, zinc — *b*, zinc sulphate solution — *c*, copper sulphate solution — *d*, copper

more than one cell in the case. If you were to go to an electric shop to get a new cell for your flashlight, you would probably ask for a "battery" instead of a cell. "Battery" is a common name for cell. A scientist uses the word "battery" to mean all the cells needed for an electric device. A battery may be one cell; it may be fifteen or more.

There are many kinds of cells. Figure 6 shows a bichromate cell. The caption under the diagram tells you what materials are used in this kind of cell. The solution acts upon the zinc and carbon in such a way that, when the carbon post is connected to the zinc post by means of a wire, a current of electricity flows through the wire. The zinc rod is often called the negative pole of the cell, and the carbon rod the positive pole.

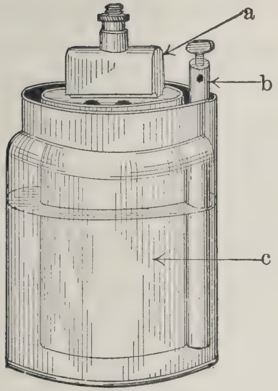


FIG. 8. A SAL AMMONIAC CELL
*a*, carbon — *b*, zinc — *c*, solution of sal ammoniac

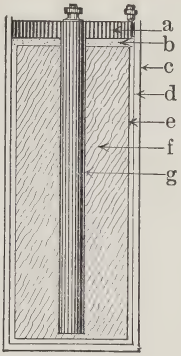


FIG. 9. SECTION OF A DRY CELL
*a*, tar — *b*, sand — *c*, pasteboard cover — *d*, zinc — *e*, paper — *f*, paste containing sal ammoniac — *g*, carbon

Figures 7 and 8 show you other kinds of cells. They are like the bichromate cells in certain ways. Each one has in it a piece of zinc. Each one has in it a piece of carbon or a piece of some other material which will serve the same purpose. And each one has in it a solution containing water and some chemical or chemicals. The chemicals correspond to the acid used in the bichromate cell.

Probably the kind of cell which you have seen most often is the dry cell. A dry cell is not really dry. Occasionally dry cells become really dry, and then they are of no use. Dry cells are called "dry" cells because they are dry on the outside. No liquid can spill from them. Figure 9 shows you how a dry cell would look if it were cut in half lengthwise. A dry cell, as you can see, is very much like a wet cell. There is a rod of carbon in it. In place of a zinc rod there is the zinc container. Notice that one binding post is fastened to the carbon rod and the other to the zinc container. Between the carbon and the zinc there is a paste made of water and chemicals mixed with flour or plaster of Paris. The heavy paper just inside the zinc absorbs the solution of water and chemicals from the paste. The solution is sure, therefore, to come in contact with the zinc.

Many different companies make dry cells, and the exact composition of the paste in these cells is usually guarded as a trade secret. It is well known, however, that one of the chemicals used in the paste is sal ammoniac.

As you doubtless have guessed, the sealing wax or tar at the top of the cell is put there to keep the water in the paste from evaporating.

When a dry cell ceases to produce a current, in most cases nothing can be done to make it usable once more. In some cases the paste has merely become too dry. If the paste has become too dry, punching holes in the bottom of the container and standing the cell in a pan of water may make the cell usable again. As a rule, however, nothing can be done to put a "dead" cell into working order.

Often some one is heard to ask if a dry cell can't be recharged. The person who asks such a question is confusing dry cells with storage batteries.

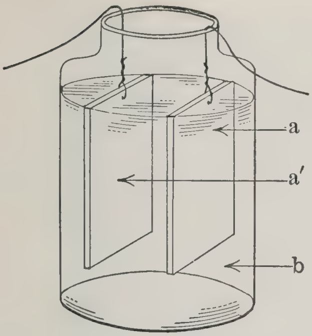


Fig. 10. A Simple Storage Cell
*a, a′,* lead plates — *b,* weak sulphuric acid

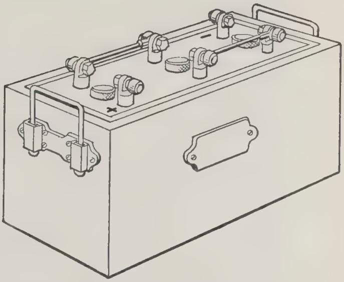
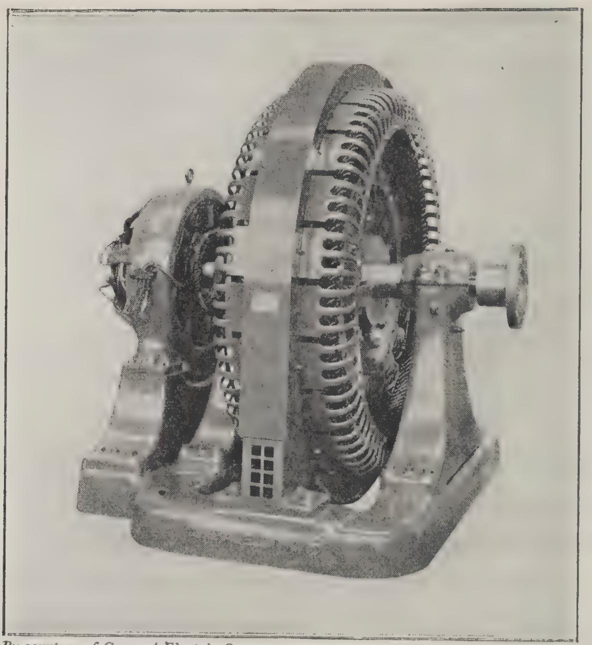


Fig. 11. A Three-Cell Storage Battery

A storage cell must be "charged" before it can be used, and it can be recharged when it becomes weak. Figure 10 shows the diagram of a very simple storage cell, one which you could easily make for yourself. As you see from the caption, the two pieces of lead are put into a weak solution of sulphuric acid. If you connect the pieces of lead to the binding posts of a bell, the bell does not ring. The cell is not producing an electric current. It must be charged. It can be charged by connecting one lead plate to the zinc post of a dry cell, and the other to the carbon post of the cell. As the current from the dry cell flows through the storage cell, a change gradually takes place in the storage cell. One of the lead plates becomes coated with a dull brown coating. The acid in the cell gradually becomes stronger, too. After the current from the dry cell has flowed

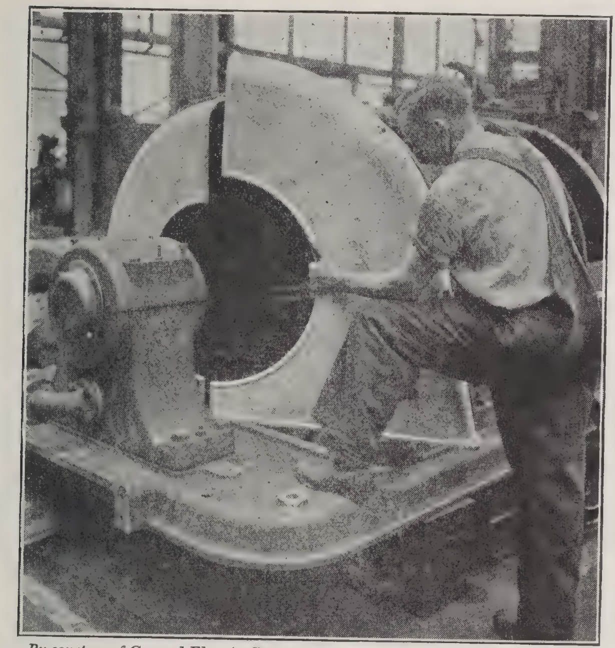


*By courtesy of General Electric Company*

FIG. 12. A GENERATOR

through the storage cell for fifteen minutes or so, the storage cell should be charged sufficiently to make the bell ring for several seconds. As the storage cell furnishes electricity to make the bell ring, the acid becomes weaker, and the brown coating on the one plate disappears. After the storage cell is "dead," it must be recharged before it can be used again.

Making such a little storage cell is interesting as an experiment, but it is easy to see that a good storage cell has to furnish more current than this little

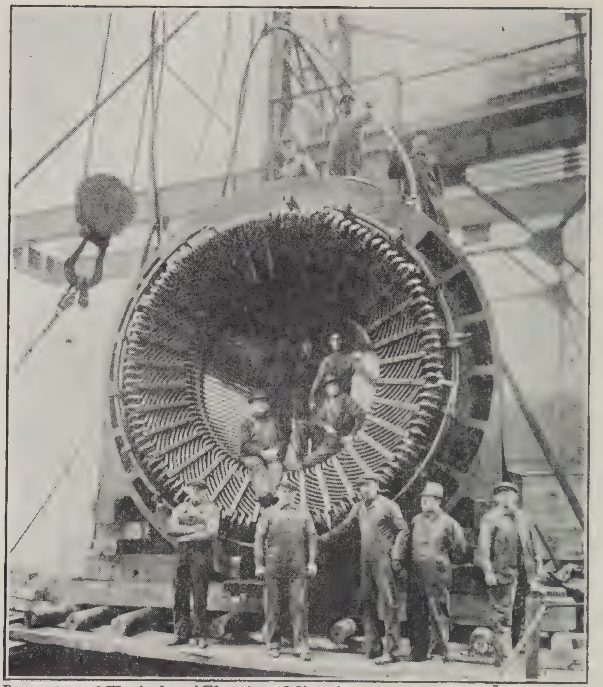


*By courtesy of General Electric Company*

FIG. 13. BUILDING A GENERATOR

one does, and has to be charged in a different way. There is no point in using dry cells to charge storage cells except as an experiment. The dry cells are soon worn out. It would be cheaper to use dry cells to ring a bell than to use dry cells to charge storage cells to be used in ringing the bell.

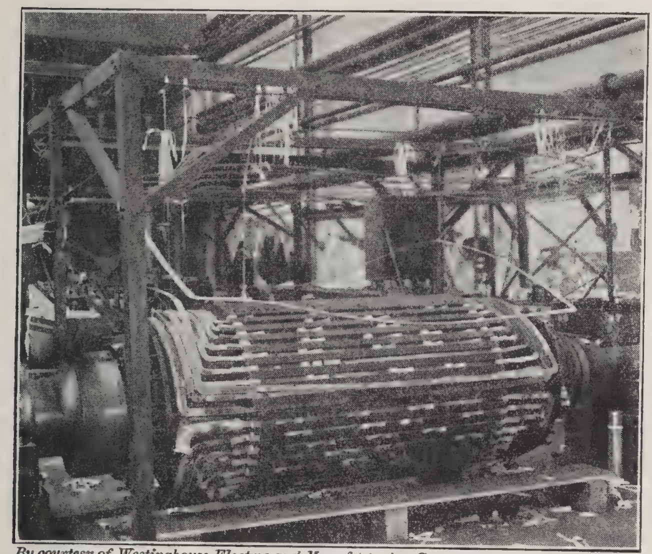
Figure 11 shows a three-cell storage battery similar to those used in autos or with radio sets. Such batteries are charged with electricity from a generator. A generator is a machine for furnishing a cur-



*By courtesy of Westinghouse Electric and Manufacturing Company*

FIG. 14. THE STATOR OF A BIG GENERATOR

rent of electricity. Sometimes generators are called "dynamos." The word "dynamo" really means both generators and electric motors. Figure 12 shows you the picture of a generator. In Figure 13 you see a generator being built. The electricity which we use for our electric lights and our electric heating devices and our electric motors comes from a power plant. Every electric power plant contains one or more generators. But a power plant contain-



*By courtesy of Westinghouse Electric and Manufacturing Company*

FIG. 15. THE ROTOR OF A BIG GENERATOR

ing no machines but generators would not furnish any power at all.

A generator is made of a magnet and a coil of wire called the armature. A small generator contains a small magnet and a small coil of wire. The magnet and coil of a large generator may weigh many tons. To generate a current of electricity, either the armature or the magnet must be made to rotate. The armature may be made to rotate while the magnet stands still, or the magnet may be made to rotate while the armature stands still. In most small generators it is the armature which turns. In most large generators the magnets turn. Figure 14 shows the

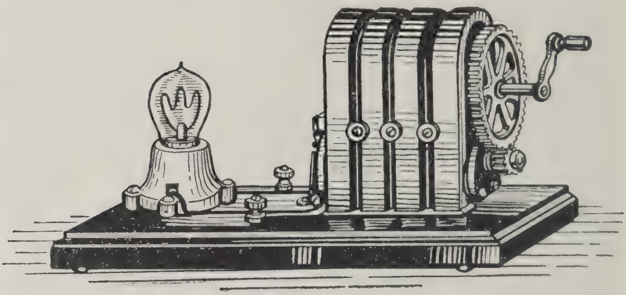
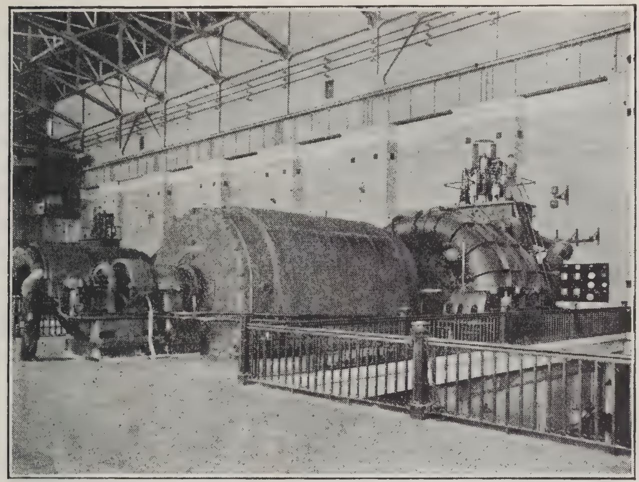


Fig. 16. A Hand-Power Generator

stator, or stationary armature, of a huge generator. Figure 15 shows the rotor, or rotating magnet, of a generator. The point to remember about generators is that, if neither the armature nor the magnet is turning, no electric current is being produced. Every power plant, therefore, must have some sort of machine for making a part of the generator rotate.

Perhaps you have seen a generator which was turned by hand. If you have had any experience with country telephones, you probably remember that you have to turn a crank to signal the operator. Turning this crank is really turning the armature of a small generator or magneto. The magneto generates a current which lights a little lamp on the switchboard at "Central." Figure 16 shows you such a hand-power generator. It is hard to imagine getting enough electric current for our electric lights and our electric heating devices and our electric motors from hand-power generators. We don't. You

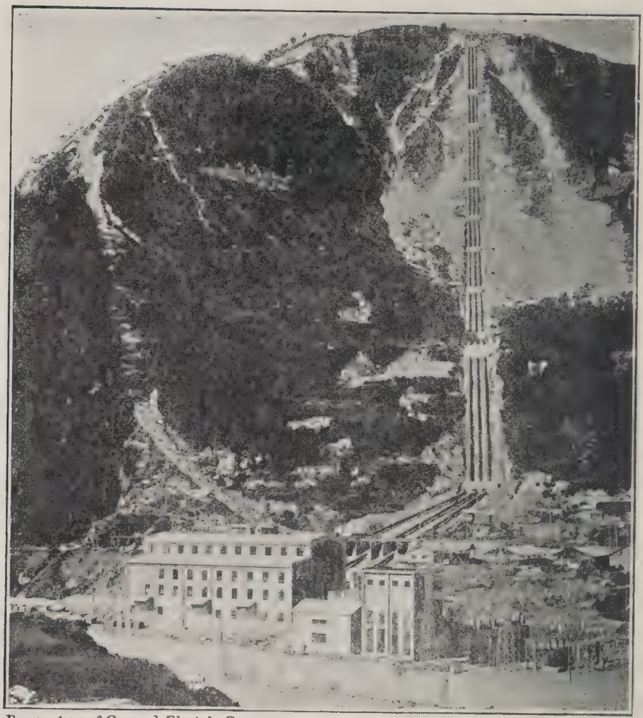


*By courtesy of Westinghouse Electric and Manufacturing Company*

FIG. 17. INTERIOR OF A POWER PLANT

needn't expect to see workmen turning the generators in a big power plant.

Using steam engines for driving generators is very common. Figure 17 shows a picture of a power plant in which the generator is driven by the kind of steam engine called a steam turbine. During the World War theaters were asked to shut off their big electric signs on certain nights in order to save coal. Many people were puzzled because they didn't understand what coal had to do with electric signs. The point is this: The electric current for the electric signs was furnished by generators. The generators were run, for the most part, by steam engines. Coal had to be burned under the boilers of the steam en-

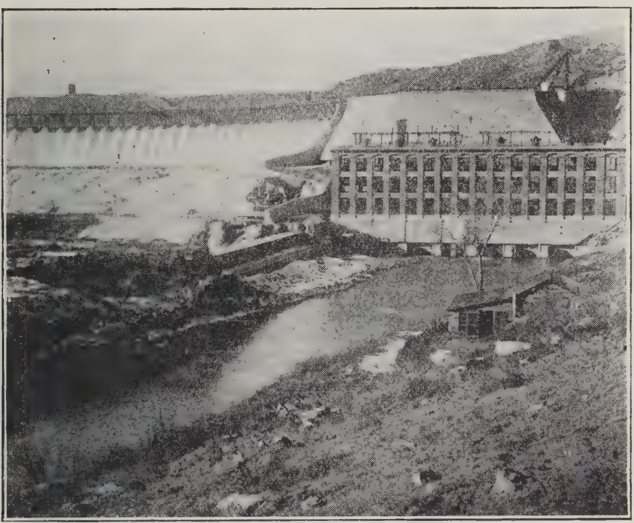


*By courtesy of General Electric Company*

FIG. 18. A HYDROELECTRIC POWER PLANT

gines to make the steam engines run. When fewer lights were used, less coal had to be burned.

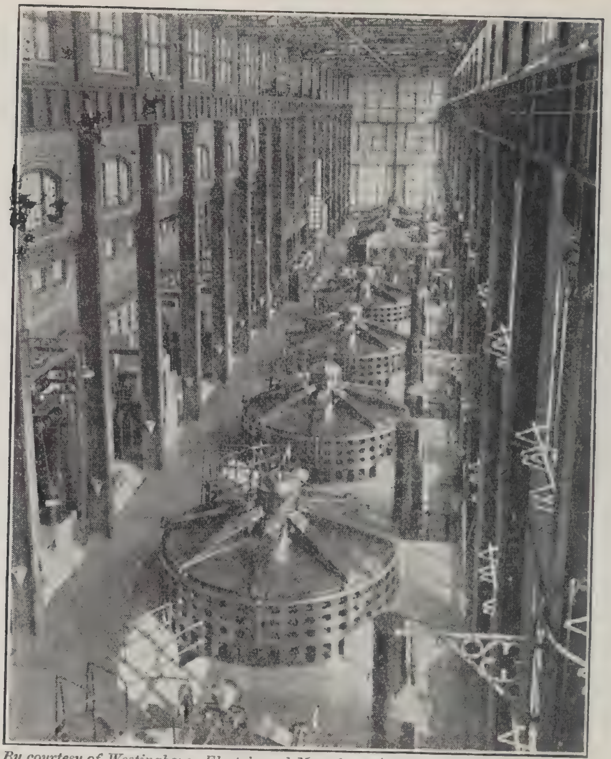
Using water power for driving generators is very common, too. A power plant in which the generators are turned by water wheels is called a hydroelectric plant. Figure 18 shows a hydroelectric plant in a mountainous region. The water rushing down the steep slope has power enough to turn the



*By courtesy of Chicago, Milwaukee and St. Paul Railway*

FIG. 19. ANOTHER HYDROELECTRIC POWER PLANT

water wheels which turn the generators. Figure 19 shows another hydroelectric power plant. Here a stream was dammed to make the water fall and drive the generators. In Figure 20 you see the interior of a hydroelectric power plant. You should be able to count seven big generators. There are huge hydroelectric plants in Switzerland, in the mountainous regions of Norway, and in our own western mountains. By no means all hydroelectric power plants, however, are in mountainous regions. Perhaps you have seen the large power plants at Niagara Falls. One of the largest hydroelectric plants in the United States is the one at Keokuk,



*By courtesy of Westinghouse Electric and Manufacturing Company*

FIG. 20. INTERIOR OF A HYDROELECTRIC POWER PLANT

Iowa. The Mississippi River furnishes the water power which drives these generators. Another very large hydroelectric plant is the Muscle Shoals Plant at Wilson Dam, Florence, Alabama. When it is possible to use water power for driving generators, it is often cheaper to use it than to use coal.

Gas engines are sometimes used to turn generators. Occasionally for some special reason an electric motor is used to drive a generator. In most cases this would be a foolish proceeding, for you would be using a current of electricity to generate a current of electricity, and it wouldn't be possible to get as much power from the generator as is used in the motor.

Many people who live in the country where they cannot get current from a big power house have small power houses of their own. Such a small power plant contains a generator, a gasoline engine, and a number of storage cells. The storage cells are not absolutely necessary, but they are convenient. The current for the house is furnished by the storage cells. The generator furnishes the current for charging the storage cells, and the gasoline engine drives the generator. If storage cells were not used, the gasoline engine and the generator would have to be working whenever a current was needed. When they were working they would require more or less watching. If storage cells are used, the generator and engine can be run at some convenient time during the day to charge the batteries. The batteries are then ready to furnish a current whenever it is needed.

Some generators furnish direct currents. A direct current is one which flows always in the same direction through the wires leading from the generator. Other generators furnish currents which flow first in one direction, then in the other. Such currents are called "alternating" currents. The currents from most alternating current generators change direction one hundred and twenty times a second. Before you buy any devices containing electric motors, you should know whether the current you plan to use for the motor is a direct current or an alternating current. All cells furnish direct currents.

There are thirty-two electrical devices listed on page 2. For most of these we use the current from generators rather than from cells. Enough cells could be connected to furnish a current strong enough for heating an electric grill, but few people would use an electric grill if they had to buy and take care of the many cells that would be needed. The same thing is true in the cases of most of the devices on the list. It is true of most of the electrical devices used outside our homes, too. Clearly, one of the very important steps in the harnessing of electricity to make it do our bidding was the invention of the generator.

## VI. THE FIRST CELL

One day, about a hundred and forty-five years ago, Galvani, an Italian scientist, was performing some experiments with frictional electricity. He had an electric machine with which he was able to get long electric sparks. In his laboratory that day he had also a pair of frog-legs. Perhaps the frog-legs were there to be put into soup. Perhaps Galvani had planned to study the nerves in the legs of the frog, for most of his studies were about nerves and bones and muscles. At any rate the frog-legs were there, and they were near the electric machine. One of Galvani's assistants happened to touch the frog-legs with a knife at the same time that he drew a spark from the electric machine. To Galvani's surprise, the frog-legs jerked in much the same way in which the legs of a live frog might jerk if you touched them. Why should they jerk? Evidently the jerking was caused by electricity.

Nothing important came of this experiment for more than six years. Then Galvani thought of another experiment which he might do with frog-legs. He would hang the legs of a frog out of doors on a stormy day and would watch to see what happened to them when there was a flash of lightning. He expected that they would jerk just as they had done when they were near his electric machine. A stormy day came. He fastened each of the frog-legs he had prepared to the end of a copper wire. He then fastened the ends of the copper wires to the iron railing of the balcony outside his window. The wind was blowing, and the frog-legs were blown against the iron rods of the balcony railing. When they touched the iron they jerked just as they had before. But there had been no lightning! And there had been no sparks from an electric machine.

Galvani decided that again it was electricity which had made the frog-legs jump. The electricity, he thought, must have been stored up in the frog. From where else could it have come? He was so sure that this experiment and others which he performed soon afterward showed that electricity was stored in the nerves and muscles of animals that he wrote a book about "animal electricity."

Volta, another Italian scientist of that time, learned of Galvani's experiments with the frog-legs. Volta agreed with Galvani that it was electricity which had made the frog-legs jerk, but he thought that Galvani's explanation of where the electricity came from was all wrong. Volta thought that the copper rod and the iron railing were much more important in the experiment than the frog-legs had been. He set about to prove that he could get electricity from two pieces of metal without using frog-legs.

At length he cut out a number of round disks of copper and others of zinc. He used zinc because he had found that zinc worked better than iron. He made a pile of these metal disks. Figure 21A shows you the arrangement of the copper and zinc disks. The pieces of flannel cloth which are shown in the diagram were moistened with water to which a little

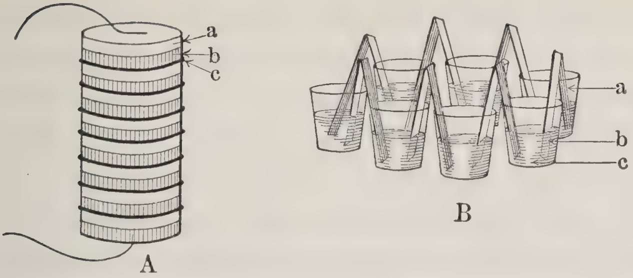


Fig. 21. Volta's Cells

*A*, voltaic pile
*a*, zinc — *b*, copper — *c*, flannel cloth

*B*, crown of cups
*a*, zinc — *b*, copper — *c*, weak sulphuric acid

acid had been added. These pieces of flannel, Volta thought, would serve the same purpose which the frog-legs had served. Of course he was very much pleased when he found that he got a little electric spark whenever he touched the wire fastened to the topmost piece of zinc to the wire fastened to the lowest piece of copper.

Volta soon decided that the pieces of wet flannel between the metal disks were a nuisance. They dried out too quickly. He must find something better. After a few experiments he discovered that he could use tumblers filled with water and acid in place of the wet flannel. Figure 21B shows his scheme for using the tumblers of water and acid. Notice that the strip of copper in one tumbler leans against the strip of zinc in the next tumbler. When one of the strips of copper was moved a very short distance away from the strip of zinc it had been touching, a tiny spark jumped across the gap. This showed that a current of electricity was being produced. This arrangement of tumblers was called "Volta's crown of cups." You can see that it was really a battery made of several wet cells. Galvani's experiment with the frog-legs wasn't very important in itself, but it led to a discovery of great importance — Volta's discovery of how an electric cell could be made.

Scientists soon learned that from an electric cell a current of electricity could be had whenever it was wanted. The current could be made to flow for a short time or for a long time just as one wished. Volta had taken the first real step in harnessing electricity to help us.

## VII. FARADAY: THE INVENTOR OF THE GENERATOR

We owe the generator to the great English scientist, Michael Faraday. Faraday did not build a huge generator like those we have to-day, but he did discover the principle upon which all generators are built. At the time that Faraday began his experiments, the only way known of getting a current of electricity was by using cells. The discovery had been made by other scientists that magnets could be made by using an electric current. When Faraday learned of these experiments, the idea occurred to him that he could use magnets in getting an electric current. "If electricity can be used in making magnets," he argued, "it should be possible to use magnets in getting electricity. It's a poor rule that won't work both ways."

At first his experiments were discouraging. Finally, however, he discovered that, if he moved a magnet in and out of a coil of wire properly arranged, a current of electricity would flow through the wire of the coil. He found, too, that the magnet might remain stationary and the wire be moved back and forth near the ends of the magnet with the same result. All that was necessary was that the wire or the magnet be moved in such a way that the wire passed through the rays of magnetic force around the magnet. The current which he produced in this experiment was very slight, but finding that a current could be produced in this way was of tremendous importance.

By no means all the people who heard of Faraday's experiment realized its importance. He was often asked, after he had explained his discovery to an audience, of what use his little generator was. Faraday himself had imagination enough to see that his discovery might play a very important part in the future of electricity. The huge generator of today is merely Faraday's first generator "grown up."

The discovery of the principle upon which the generator is based is probably Faraday's most important discovery in the field of electricity, but it is by no means his only one. He made so many that he has been called the founder of electrical science.

Faraday became interested in electricity when he was only a boy. He was a poor boy who lived in London. His father was a blacksmith. When Faraday was twelve he was hired as an errand boy for a bookbinder. While he was in the shop, he came across many books about science. He found time to read many of them. A customer one day watched him poring over an article on electricity in an encyclopædia. The man was so much impressed with the boy's interest in electricity that he gave him tickets to four lectures about electricity. These lectures were given by Sir Humphry Davy, one of the very great scientists of that time. Faraday took notes while he listened to the lectures and later wrote the notes very carefully in a book. Before this time he had decided that he would like to spend his life studying science. After he heard Sir Humphry Davy's lectures he wrote to Davy about his ambition to become a scientist. He sent his book of lecture notes with his letter. Davy was so greatly pleased with the notebook that he promised to have a talk with Faraday.

We can imagine how happy Faraday was when one night Davy's splendid carriage stopped at Faraday's door, and the servant delivered a message asking Faraday to call upon Davy the next day. You may be sure that Faraday did. Davy engaged him as an assistant.

This was the beginning of Faraday's fifty-four years of work with science. Some of his experiments had to do with chemistry, some with magnetism, and some, as you know, with electricity. He kept a record of all the experiments he performed. In all there were sixteen thousand forty-one.

The list of his important achievements is very long. Even if he had not found a new way of generating electric currents, he would rank as one of the very great scientists. Sir Humphry Davy was once asked what he considered the most important of all his own important discoveries. Davy's answer was, "Michael Faraday." Do you wonder?

## VIII. BELL CIRCUITS

One lesson which you very soon learn by experimenting with electrical apparatus is this: A current of electricity will not flow from a cell or a generator unless there is a path by which it can get back to the cell or generator again. There must be a complete path from one binding post of the cell or generator to the other binding post of the cell or generator. Such a path is called a complete circuit.

If you hold an electric doorbell in such a way that each binding post of the bell touches one binding post of a dry cell, a current flows through the bell and the bell rings. But if one binding post of the bell is lifted a tiny bit away from one binding post of the cell, the bell stops ringing. There is no longer a complete circuit. The circuit has been broken.

Perhaps you are surprised to find that no wire is necessary to make a doorbell ring. In most cases where one uses a bell, however, wire is used. For a doorbell it would, of course, be possible to have just a dry cell and a bell at the door. Each caller would then have to hold the binding posts of the bell against the binding posts of the cell. You do not need to be told the many reasons why this plan would not be a good one. It is easy to see that some scheme is needed by means of which a person at the door can ring a bell inside the building. A longer pathway for the electric current has to be provided. Figure 22 shows how this can be done. Notice that when the two ends of the wires are made to touch each other, there is a complete circuit for the electric current. The bell then rings. As soon as the two ends of the wires are separated, the circuit is broken. Since there is no longer a complete circuit, the current ceases to flow, and the bell stops ringing.

In wiring a house for a doorbell, one might leave two ends of wire sticking out from the wall near the door. The caller would need only to push the two

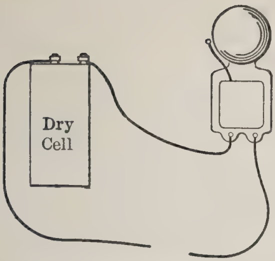


FIG. 22. A BROKEN CIRCUIT

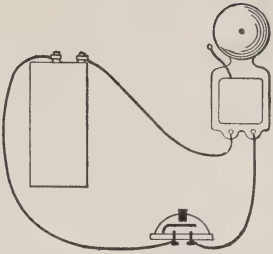


FIG. 23. A DOORBELL CIRCUIT

ends together to make the bell inside ring. But such loose ends of wire might often be made to touch each other accidentally. They would be broken off easily; and certainly two loose ends of wire are not decorative. Therefore, instead of letting two loose ends of wire stick out, we use a push-button. A push-button, as you see from Figure 23, contains a strip of metal and two screws. The end of one wire is connected to one screw. The end of the other wire is connected to the other screw. When the button is pushed down the piece of metal touches both screws. Pushing down the button is just like pushing the ends of the two wires together. The circuit is complete and the bell rings. When the button is released, the strip of metal springs away from the screws and the circuit is broken. A push-button is really, you see, merely a device for making and breaking the circuit.

Sometimes a complete circuit is spoken of as a "closed circuit," and a broken circuit as an "open circuit."

If you went to an electric shop and asked for wire for wiring an electric bell, the salesman would be sure to give you copper wire. Do you know why? Why not use iron wire? Why not use silver wire? Why not use cotton string?

Before you can answer these questions you must know that a current of electricity flows through some substances much more easily than through others. Materials through which it flows easily are called good conductors of electricity. Materials through which it does not flow easily are called poor conductors.

If you connect a bell and cell as shown in Figure 24, you can easily test many materials for yourself to find out whether they are good or poor conductors. Suppose you wish to test cotton. Fasten a piece of cotton string from *A* to *B*. If cotton is a good conductor, the bell will ring. If the bell doesn't ring, cotton is not a good conductor. Some substances are such very poor conductors that they are called insulators. Cotton is one of these. A pathway of cotton is really no pathway at all.

Such tests show that all the metals are good conductors. Carbon is a fairly good conductor. A complete list of good conductors must include damp ground, a mixture of water and acid, and solutions of

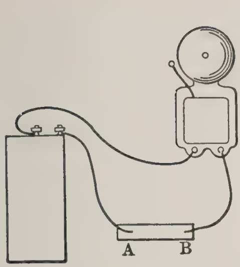


Fig. 24. Diagram Showing how to Test Materials for Conductivity

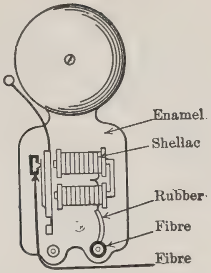


Fig. 25. Diagram to Show Insulation Used in an Electric Bell

various salts and water. The way of testing shown in Figure 24 does not show you that all good conductors are not equally good conductors. Scientists have found out in other ways that copper, for example, is a much better conductor than iron, although iron is a good conductor. Silver, moreover, is a better conductor than copper. If silver wire weren't so expensive, we should use silver wire in many places where we now use copper.

Dry wood, paper, alcohol, kerosene, and *pure* water are poor conductors. Among the materials which are such poor conductors that they are called insulators are hard rubber, mica, amber, glass, porcelain, sulphur, dry air, bakelite, shellac, and soft rubber.

When Dr. Gilbert, of whom you read in the chapter about electrical charges, tried to get electric sparks by rubbing rods of metal, he didn't succeed. He said that metals were "non-electric." He could get electric sparks, as you doubtless remember, by rubbing amber and glass and sealing wax. Now that you know that some substances are good conductors and some are poor conductors of electricity, you can understand why. When he rubbed rods of metals, all of which are good conductors of electricity, the electric charges escaped through the rods as fast as he could generate them by rubbing. When he rubbed amber or glass or sealing wax, the charge did not escape through the rod because the material of which the rod was made was a very poor conductor.

Insulators are just as important in work with electric currents as good conductors are. They can be used to prevent the current from going where you do not wish it to go. Of course, if you are careless, insulators may prevent the current from going where you do wish it to go. In the diagram in Figure 25, the insulating materials used in an electric bell are indicated. If it were not for this insulation, the current would not follow the right path through the bell, and the bell would not ring.

Practically all the electric wiring about our houses is done with insulated wire. Insulated wire is wire covered with some kind of insulator. In some cases rubber is used. Some wire is painted with shellac. Some wire is insulated with silk. Some wire has one or more layers of cotton thread wrapped around it.

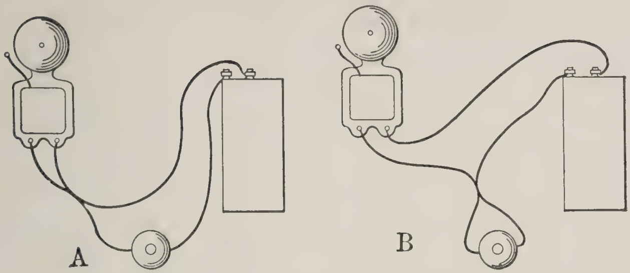


Fig. 26. Two Short Circuits

Rubber-covered wire is perhaps the most common kind of insulated wire.

The purpose of covering wire with an insulator is to prevent short circuits. Suppose two wires happened to touch as shown in the diagram in Figure 26A. If the wires were bare, most of the current from the cell would go from one wire to the other when the push-button was pushed, and would get back to the cell without going through the bell. Of course the bell would not ring. Whenever electricity gets back to a cell or a generator by a shorter or an easier path than the one it is supposed to take, we call the circuit a short circuit.

A short circuit in a bell circuit does not always keep the bell from ringing. It may make it ring all the time. The short circuit shown in Figure 26B is such a short circuit.

Perhaps you have tried at some time to connect a bell, a cell, and a push-button, and found that the bell did not ring when you pressed the push-button.

The following questions may help you find out what is wrong in such a case:

Is there a short circuit?

Has the insulation been removed from the ends of the wires where the wires are connected to the binding posts? (If it has not, the insulation will prevent the current from flowing.)

Is the cell good?

Is the bell in working order? (If the bell rings when you hold the binding posts of the bell against the binding posts of the cell, both the bell and the cell are good. If the bell does not ring, either the bell is not in working order, or the cell is dead.)

Are the binding posts screwed down tight so that there is a good connection at each one?

Is the wire broken anywhere? (Occasionally breaks in the wire do not show because the insulation keeps the ends of wire from falling apart. If you find a break in the wire, the two ends of wire can be spliced together. The insulation should be removed for about an inch on each side of the break. Then the bare ends of wire should be twisted together.)

It sometimes happens that if the circuit is long a single cell does not furnish a current strong enough to ring the bell. If the current is not strong enough to make the bell ring, a better cell should be used, or a second cell should be added to the circuit. Ex-

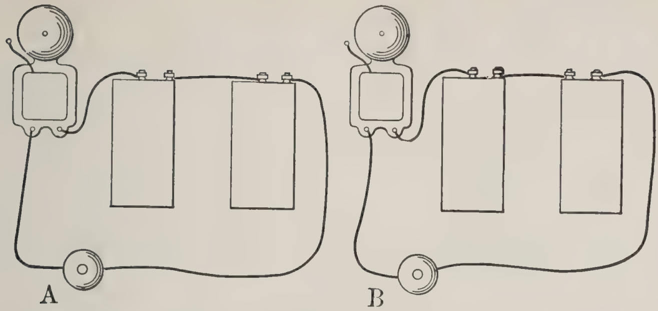


FIG. 27. A RIGHT WAY AND A WRONG WAY OF PUTTING TWO CELLS IN A CIRCUIT

perimenting will show you that, if you use two cells, they should be connected as shown in Figure 27A. If the carbon post is connected to the carbon post, and the zinc post to the zinc post, as shown in Figure 27B, the bell does not ring because no current flows.

A bell circuit may be very much more complicated than the circuit shown in Figure 23. Suppose you have a playroom on the third floor of your house and you wish to wire it for a doorbell so that your mother can call you from your playroom by pressing either a push-button on the first floor or one on the second floor. The first thing to do is to make a plan for connecting the cell, bell, and two push-buttons. After your plan is made, you should check it by tracing the path of the current in your circuit. Find out first whether or not the current can get back to the cell before either push-button is pushed down. If it can, the bell will ring all the time. If there is not a

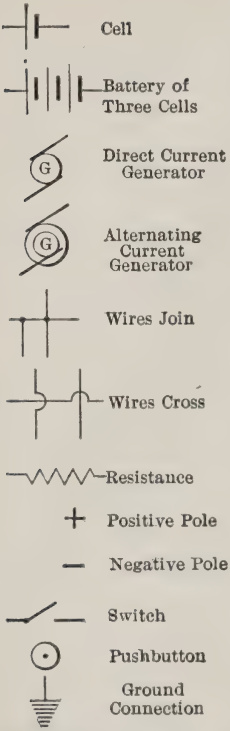


FIG. 28. SYMBOLS USED IN ELECTRICAL DIAGRAMS

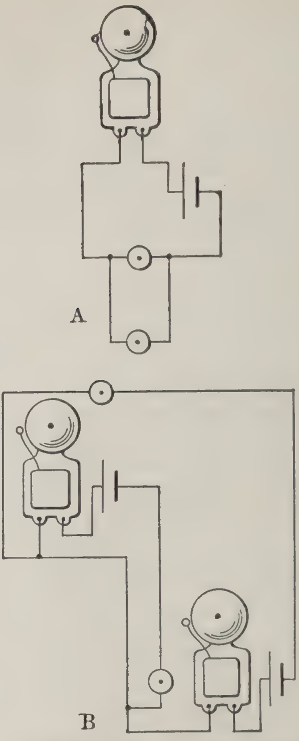


FIG. 29. TWO SIGNAL CIRCUITS

short circuit, imagine that you are pushing down one of the push-buttons. Trace the path of the current. Is there a complete circuit? Imagine you are pushing down the other push-button. Is there a complete circuit? Remember that a current cannot flow through a push-button unless it is pushed down.

When electricians draw diagrams to show how

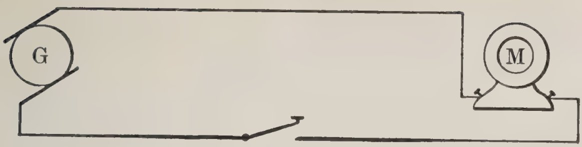


FIG. 30. A MOTOR CIRCUIT

connections are to be made, they do not take time to draw pictures of all the apparatus. They use symbols to stand for the apparatus they use. Figure 28 shows some of the commonly used signs. Figure 29A shows a correct plan for wiring a bell, cell, and two push-buttons, translated into the sign language of electricians. Figure 29B shows a signal system with a push-button and bell at each end of the line.

Most of this chapter has had to do with connecting bells and cells and push-buttons. All that you have learned about bell circuits will help you, however, not only in connecting bells, but also in connecting motors or telegraph instruments or any other electrical apparatus you use.

Figure 30 shows a motor circuit. Notice that it is really just like the bell circuit shown in Figure 23. The current which flows through this circuit is furnished by a generator. The switch is used to make and break the circuit just as the push-button does in the bell circuit.

Knowing about broken circuits and short circuits should help you find the difficulty when electrical apparatus fails to work as it should, and should help you understand some of the experiences you have had. Perhaps you have heard an automobile going down the street with the horn blowing continuously, although the driver wasn't pushing the button at all. This happens when there is a short circuit in which the push-button is cut out of the circuit. The circuit is much like that shown in Figure 26B. Perhaps your electric iron has failed to work because one wire was broken. Perhaps a fuse has blown out when the insulation was worn off the wires of an electric lamp cord and the two wires of the cord touched each other and made a short circuit. You will be told in a later chapter why a fuse blows out when there is a short circuit of this kind. Perhaps you have been on a street car when all the cars along the line were stopped by the breaking of a trolley wire.

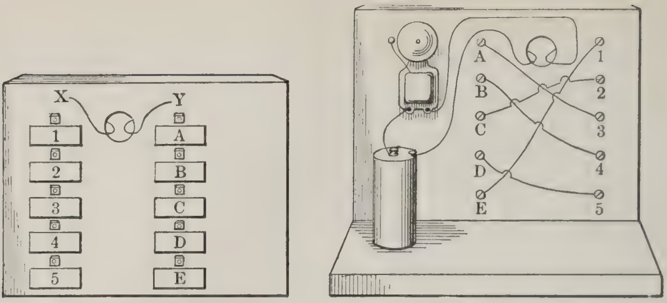
You may have had an experience with your telephone similar to the following one. A telephone operator kept getting a signal indicating that some one at a certain number was trying to put in a call. She answered but got no response, although the light continued to burn. She finally had to send out a "trouble-man" to see what was wrong. He found that a scrubwoman had got the insulation on the wires leading to the telephone very wet when she had scrubbed the floor that morning. The wet insulation had provided a short circuit for the current.

You may not have had any such experiences with electrical apparatus which failed to work as it should. At any rate, knowing about electric circuits helps you understand such things as how a motorman, by simply moving a lever, can start and stop a trolley car, why an electric fan doesn't run unless the switch is closed, and how merely pushing a button on the wall can send an electric current through the lamps and flood a room with light.

## IX. MAKING AN ELECTRIC QUESTIONER AND A BURGLAR ALARM

An electric questioner is a simple application of what you have been told about electric circuits. Figure 31 shows a plan for a homemade electric questioner. Any wooden box which is large enough will serve as the framework, or two pieces of wood may be nailed together in such a way that one serves as a base and the other is upright. On one half of the front side of the questioner there are questions; on the other half are answers to these questions.

Small stove bolts make good binding posts. To use the questioner you hold the end of the wire marked *X* on the binding post above the question you wish to have answered. You then touch the end *Y* to one binding post after another on the answer half of the questioner. When the wire touches the binding post above the correct answer, the bell rings. To make this possible, on the back of



Front View Back View

FIG. 31. A HOMEMADE ELECTRIC QUESTIONER

the questioner wires join each question to its answer. If, for example, answer *A* answers question 3, a wire is put from 3 to *A*, as the diagram shows. When the end of one wire is held on the binding post above 3, there is not a complete circuit until the end of the other wire touches the binding post above answer *A*.

Of course you can have many more questions and answers than the diagram indicates. An excellent plan is to have several different sets of questions and answers. This can be done if you paste your questions and answers on pieces of cardboard instead of on the wood. The pieces of cardboard must be the size of the front of the questioner, and must have holes punched in the proper places so that the binding posts can come through. Instead of questions you might use small pictures of birds or insects or flowers or trees. In that case you would have the names of the birds, trees, flowers, or insects in place of answers.

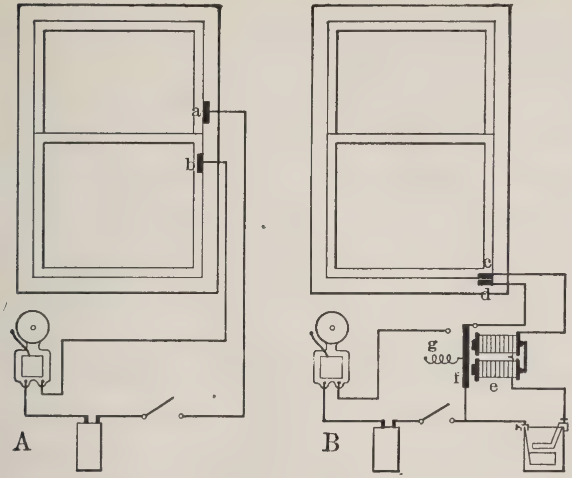


Fig. 32. Two Burglar Alarm Circuits
*a, b, c, d,* pieces of metal — *e,* electromagnet — *f,* armature — *g,* spring

Figure 32 A shows a very simple burglar alarm circuit; *a* represents a strip of copper or brass on the window frame; *b* represents a similar piece of copper or brass on the window sash. When the window is raised, the two pieces of brass or copper come in contact with each other, and the circuit is complete, provided the switch is closed. A switch is put in the circuit so that the window may be opened during the daytime without making the bell ring. If you wish to experiment with burglar alarm circuits, you will find that a box with a sliding cover serves very well for testing your plans. The lid, of course, represents the window sash, and the box the frame work.

The objection to a burglar alarm circuit like the one shown in Figure 32A is that the wire might be cut, and then the alarm would not work. Figure 32B shows a much better burglar alarm circuit. This circuit you will be able to understand after you have learned how electromagnets work.

## X. MEASURING ELECTRICITY

If you have an automobile, you have probably noticed the ammeter on the instrument board in the front of the car. This ammeter shows how rapidly electricity is being furnished to the storage battery by the generator, or how rapidly electricity is being furnished by the storage battery to the lights or horn or starting motor. Many ammeters are so built that whenever the hand moves to the right of zero, the battery is being charged. Whenever the hand moves to the left of zero, the battery charge is being used up. The word "ammeter" is short for "ampere meter." Of course the word "meter" means "measure." The ampere is the unit by which we measure the flow of electricity. It was named in honor of the great French scientist, Ampère. We talk about strong currents and weak currents of electricity just as we say that a room is either hot or cold. But, if we wish to tell how strong or how weak an electric current is, we must measure it in amperes, just as, in order to tell exactly how hot or how cold a room is, we must measure the temperature in degrees. If we wished to tell how rapidly a big tank of water was being emptied, we might say, "The water is flowing out of the tank at the rate of ten gallons a second." In the same way, if we wished to tell how rapidly we were using electricity from a battery or a generator, we might say, "The current is two amperes." If you use a current of two amperes from the storage battery of your car, it will run down much sooner than if you use a current of one half ampere.

If you look at your electric iron or at your sewing-machine motor or at almost any one of the electrical devices you have in your home, you will find that it is marked to tell how strong a current is needed to make the device work as it should. The mark on an electric iron, for example, may tell you that the iron needs a current of four and one half amperes. The ordinary sixty-watt electric lamp requires a current of one half ampere. A telephone receiver operates on less than a tenth of an ampere, while the motor of a trolley car may draw as much as forty or fifty amperes. A common electric bell needs a current of about one tenth ampere.

Suppose you have wired a bell, a cell, and a push-button, and find that the current flowing through the circuit is not strong enough to make the bell ring. Perhaps, if you used an ammeter, you would find that the current is only one twentieth ampere instead of the one tenth ampere which is needed. What can be done to make the current stronger? What, in other words, can be done to make a greater quantity of electricity flow through the circuit in a given time? One way of making the current stronger is to lessen the resistance in the circuit. By "resistance" is meant any opposition to the flow of the current. In every circuit there is some resistance, because no substance is a perfect conductor of electricity, but in some circuits the resistance is very much greater than in others.

Copper, as you were told in a previous chapter, is a much better conductor of electricity than is iron. Another way of saying this is that iron offers more resistance than copper. If you were using iron wire to connect the cell, bell, and push-button, you could lessen the resistance in the circuit by using copper wire of the same size instead.

If you were already using copper wire, the resistance in the circuit might be lessened by using larger copper wire. If the larger wire had twice as large a diameter as the first wire, it would offer only one fourth as much resistance.

The resistance might be lessened by shortening the pieces of wire used in the circuit. A wire ten feet long offers twice as much resistance as a similar wire five feet long.

If any of the connections were carelessly made, the resistance might be lessened by making better connections.

The device to be operated by the electric current always offers considerable resistance. You might be able to substitute for the bell in your circuit a bell which offered less resistance.

Perhaps, even by reducing the resistance in the circuit, you cannot make the current strong enough to make the bell ring. A second way of increasing current strength is to increase electrical pressure. Electricity doesn't flow through any circuit unless there is electrical pressure to force it to do so. It is just as if the electricity had to be pumped through the circuit. Cells or generators serve as the "pumps." If the electrical pressure of one cell is not great enough to force a current of the right amperage through the circuit, two cells may be used. On page 50 you were told of this way of increasing the strength of a current. Even more cells could be put in the circuit if necessary.

The whole story of how the strength of a current may be regulated can be told in few words: The strength of the current in a circuit depends upon the electrical pressure, or electromotive force as scientists call it, and the resistance. If the resistance stays the same, the greater the pressure, the stronger the current. If the electrical pressure or electromo-

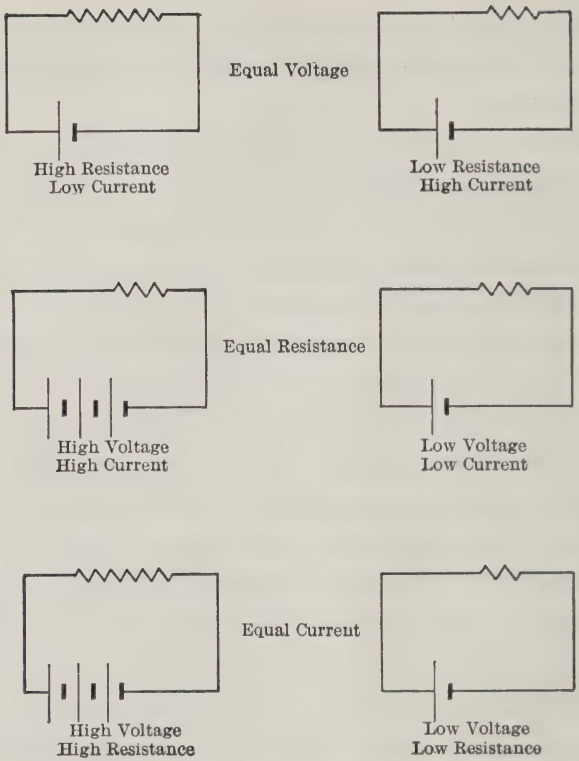


Fig. 33. Diagrams to Show the Relation between Voltage, Resistance, and Current Strength

tive force stays the same, the greater the resistance, the weaker the current. If you wish the current to remain the same, you must increase the pressure if you increase the resistance. Similarly, if you wish the current to remain the same, you must increase the resistance if you increase the pressure. The diagrams in Figure 33 may help you understand the relation between resistance, pressure, and current strength.

You have probably seen and heard the words "volts" and "ohms." Electromotive force (electrical pressure) is measured in volts. Resistance is measured in ohms. Volts were named in honor of Volta, who, as you have been told, made the first electric cell, and ohms were named for the German scientist, Ohm, who studied electrical resistance. The voltage of a common dry cell is nearly one and one half volts. The voltage of one cell of a storage battery is about two volts. If the battery contains three cells properly connected, the voltage of the battery is about six volts. The current for lighting a building is, as a rule, delivered at 110 or 220 volts, while street cars operate on from 400 to 600 volts. Voltage is measured with a voltmeter. The resistance of a small electric bell is about three ohms, the resistance of a telephone receiver is about sixty ohms, and that of an ordinary sixty-watt electric lamp is about 220 ohms.

The scientists' way of expressing the relation of resistance and pressure to the strength of the current in a circuit is this:

$$\text{Amperes} = \frac{\text{volts}}{\text{ohms}}$$

This means that the number of amperes is equal to the number of volts divided by the number of ohms.

If the electromotive force is one hundred volts and the pressure is one hundred ohms, a current of one ampere flows through the circuit.

Since it is voltage which determines in part the strength of a current, you should find out what voltage is needed for sending a current of the right strength through any piece of electrical apparatus you use. The voltage of an ordinary dry cell when new is, as you have been told, about one and one half. If you are using a six-volt lamp, you would need four dry cells. If you should use an electric lamp which was intended for a 110-volt circuit on a 105-volt one, the current would not be quite so strong as it should be. The lamp would not give quite so much light as it was supposed to give. If the same lamp were used on a 116-volt line, it would give somewhat more light than it was supposed to give, but it would wear out much sooner than if it were used on a 110-volt line.

If you were to try to use a toy motor which was meant to operate on three volts on the 110-volt lighting circuit, so strong a current would flow through the motor that the wires of the motor would become very hot, and the motor would probably be ruined. At any rate, the fuse in the circuit would blow out. It would be equally disastrous to use an electric iron which was meant for a 110-volt circuit on a 220-volt circuit. Most household appliances are made to be operated on 110–115 volts. They are so built that a pressure of 110–115 volts sends a current of the right strength through them.

If you are using cells to furnish the current and the voltage is too high, the remedy is simple: Take some of the cells out of the circuit. If you are using the current from the generators at a power plant, the problem is not so simple. Suppose you wish to use the current of the electric light circuit instead of cells for ringing your doorbell. An ordinary doorbell, you remember, requires a current of only about one tenth ampere. A voltage of 110 would force a very much stronger current than that through the bell. If you understand what you have been told about the relation between pressure, resistance, and current strength, you will see that the current in the circuit can be reduced if extra resistance is put in the circuit. Rheostats are devices for regulating the resistance in a circuit. They do not reduce voltage; they merely furnish so much resistance that the strength of the current is lessened. If enough extra resistance were put in the circuit, the voltage of 110 would not force too strong a current through the bell.

The usual way, however, of using power from the lighting circuit for such a device as a bell is to use a step-down transformer. Figure 34 shows a diagram of such a transformer. Notice that the cur-

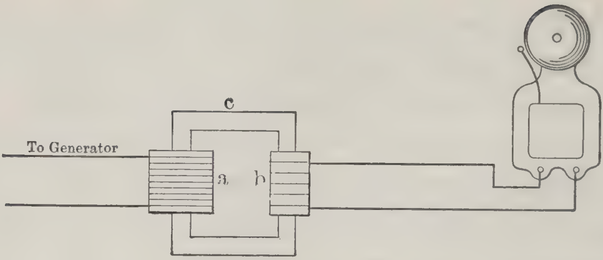


FIG. 34. A TRANSFORMER
*a*, primary coil — *b*, secondary coil — *c*, iron core

rent from the generator does not flow through the bell. It flows through the fine wire of the primary coil of the transformer only. Such a transformer is used with an alternating current. As the current flows back and forth through the primary coil, a current flows through the larger wire of the secondary coil. This current is called an induced current. The voltage on this circuit is less than the voltage on the electric light circuit. The current flowing through the secondary coil is greater, however, than the current flowing through the primary coil. The amperage of the current flowing through the primary coil is very low, that in the secondary coil is higher and is just right for the bell. A step-down transformer is really, you see, a device for trading volts for amperes. Figure 35 shows two step-down transformers. You may have used a small transformer much like the one in Figure 35B in running electrical toys.

There are step-up transformers, too. A step-up

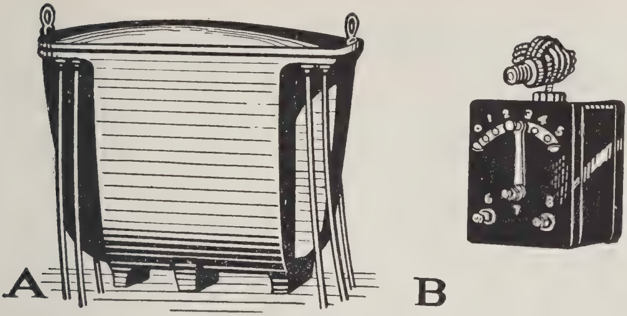


Fig. 35. Two Step-Down Transformers

transformer is just the opposite of a step-down transformer. In a step-up transformer there are more turns of wire in the secondary coil than in the primary coil, and the wire in the secondary coil is smaller. A step-up transformer is a device for trading amperes for volts. When a current of electricity is to be sent a long way, less electricity is wasted if the voltage is high and the amperage low, than if the voltage is lower and the amperage higher. Therefore, if the power from an electric power plant is to be used far away from the plant, step-up transformers are used at the power plant. The voltage may be stepped up to 1100, 2200, or even to 60,000 or more volts. At the other end of the high voltage line, there is at least one step-down transformer, where volts are traded back for amperes. The diagram in Figure 36 shows such a line for long-distance power transmission.

You have been told that, if one cell doesn't furnish

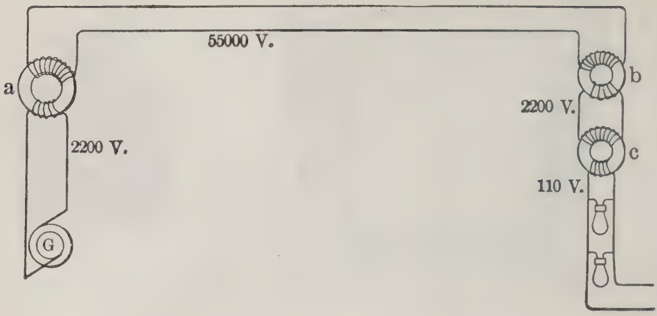


Fig. 36. Diagram of a Power Line
*a*, step-up transformer — *b*, step-down transformer — *c*, step-down transformer

a strong enough current to ring an electric bell, two cells may be used. Figure 27 A on page 51 showed how to connect these cells. If the voltage of one cell is one and one half, the voltage on the circuit in the diagram is three volts. This way of connecting cells is called connecting them in "series." It is possible to connect cells in such a way that the voltage on the circuit is no greater than the voltage of one cell. The diagram in Figure 37 shows how this can be done. This way of connecting cells is called connecting them in "parallel." Notice that, although carbon posts are connected and zinc posts are connected, the connection is not the one you were warned against on page 51. As you might expect from the fact that the voltage is not higher, the strength of the current flowing through the circuit in Figure 37 is no greater than if only one cell

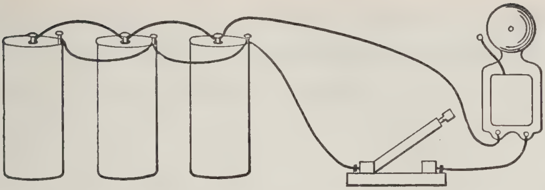


FIG. 37. ARRANGEMENT OF CELLS IN PARALLEL

were used. The only advantage of such a connection is that the cells will not wear out so soon. They will probably furnish a current for a somewhat longer time than if two cells were used, one after the other.

There are two ways of buying electricity for running an electrical device. You can buy cells at so much per cell, or you can buy electric power from a power house at so much per kilowatt hour. The electric meter in your house measures the electricity you use in kilowatt hours. If you look at your electric light bill, you will see that the readings are given in kilowatt hours.

What is a kilowatt hour? To understand what a kilowatt hour is, you must first understand what a kilowatt is. The amount of work an electric current can do in a given time depends upon both voltage and amperage. We measure electric power in watts. If the current is a direct current, you can figure power by multiplying volts by amperes. Thus, if your electric lighting circuit is a 110-volt direct-current circuit, and your electric iron uses a current of four and one half amperes, the amount of power used is 110 times four and one half, or 495 watts. In an alternating-current circuit, the number of watts is not so easy to figure. It can be found by using a meter. Probably you have seen the word "watt" on the tiny labels pasted on electric lamp bulbs. Most electric heating devices and motors are marked in volts and amperes and you have to figure the watts or read the meter if you wish to figure the cost of operating the device. Lamps are usually marked in watts. A sixty-watt lamp requires four times as much power to operate it as a fifteen-watt lamp needs. It costs, moreover, four times as much to operate the sixty-watt lamp. A kilowatt is merely one thousand watts. Usually it is not important for you to know the number of watts required for operating an electrical device unless you wish to figure the cost of running it.

Knowing that you have ten hundred-watt lamps in your house and that you have used electricity for no other purpose than for lighting those lamps still wouldn't tell you how much your electricity for a month would cost you. You have to know, too, for how many hours you used the lamps. The power required for the ten lamps is one thousand watts. This is the same as one kilowatt. Suppose that, in the course of the month, you had used these lamps for one hour only. You would then pay the light company for one "kilowatt hour." If you used only one of the lamps and used it for ten hours, you would pay for one kilowatt hour. If you burned all the lamps for ten hours, you would pay for ten kilowatt hours.

Whenever you wish to figure the cost of running an electrical appliance on the lighting circuit, find out what the electric power company charges per kilowatt hour, and how many watts are used in operating the appliance. Suppose the power company charges ten cents per kilowatt hour. You wish to find out how much it costs to run an electric iron which uses five hundred watts. This is half a kilowatt. If you used the iron for an hour, the meter would register half a kilowatt hour more than it registered at the beginning of the hour. The iron can be used for an hour, therefore, for five cents.

You can easily learn to read a kilowatt hour meter so that you can check your electric light bills. Figure 38 shows the dials on such a meter. Notice that the dials are marked 10000, 1000, 100, 10. Just as the second hand of a watch makes a whole revolution while the minute hand moves one space forward, so the 10 hand on the kilowatt-hour meter has to go around the dial once while the 100 hand moves forward one space. The 100 hand moves around once while the 1000 hand goes forward one space, and the 1000 hand moves around once as the

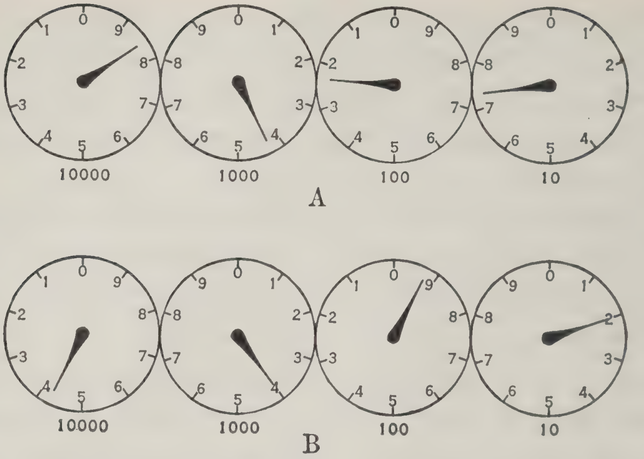


FIG. 38. TWO READINGS OF A KILOWATT HOUR METER

10000 hand moves forward one space. The hands of adjoining dials move in opposite directions. In reading the meter, start at the left and read the number which the hand of each dial has just passed. The reading of the meter in Figure 38A is 8427. Only when the pointer is very close to a number is the meter hard to read. If the pointer is very close to a number, it is necessary to look at the next lower dial to see whether the hand there is just completing one revolution or is just starting on another. The reading of the dial in Figure 38B, for example, is 4392, not 4492.

If your meter read 5000 kilowatt hours the first of this month, and 4900 kilowatt hours the first of last month, your bill will be for one hundred kilowatt hours. An electric light bill as a rule tells how much the power company charges per kilowatt hour. In many cases the scale of rates is a sliding one. For example, the scale of one big electric light company is:

9 cents per kw. hr. for the first 30 kw. hrs.
6 cents per kw. hr. for the second 30 kw. hrs.
3 cents per kw. hr. for the remainder

There are many units used in measuring electricity which are not mentioned in this chapter. Even those explained here may be somewhat confusing. Perhaps the following summary will help you:

Current strength or rate of flow is measured in amperes.

Electrical pressure or electromotive force is measured in volts.

Resistance is measured in ohms.

Electrical power is measured in watts or kilowatts.

Electricity from power plants is paid for by the kilowatt hour.

## XI. DANGERS IN USING ELECTRICITY

A clerk in an electric shop was much amused one day when he heard a mother refuse to buy her small son a dry cell for fear he might accidentally kill himself with it. Many people are very much afraid of an electric current just as this boy's mother was.

Of course there is some reason for being afraid of a powerful electric current. From time to time the papers tell of some one who has been killed by an electric current. The fact that people have been killed by powerful electric currents is, however, no reason for being afraid to use a dry cell. Being afraid to use a dry cell is just as foolish as it would be to be afraid of a gentle breeze because many people have been killed by tornadoes. Even a current strong enough to give you an unpleasant "shock" is not necessarily dangerous. Many people get electric shocks without being hurt in any way by them; but, since some shocks are dangerous, and since electricity may do harm in other ways also, everyone should know something about what the dangers in using an electric current are.

An electric current cannot hurt you unless it flows through some part of your body. Another way of saying this is that you cannot be hurt by an electric current unless your body is a part of the circuit through which the current flows. If the current passes through your entire body it is much more likely to injure you than if it flows through only a small part of your body. In the ordinary trolley car circuit, the rails of the car track serve as the return wire. The current which operates the car flows from the generator through the trolley wire to the trolley pole, through it to the motor of the car, from there to the track, and through it back to the generator to complete the circuit. Although a powerful electric current may be flowing through the rails of the track, you needn't be afraid of stepping on the rails of an ordinary street car track. When you are just touching this one "wire," your body is not a part of the circuit and no current flows through it. If, however, the trolley wire were broken and dangling and you took hold of the end of the wire leading from the generator while you were standing on one of the rails of the track, that would be a different story. Your body would then be a part of the circuit. A strong enough current might flow through your body to injure you seriously. How serious a shock you would get would depend partly upon how well insulated you were from the track. A barefoot boy who took hold of the trolley wire while he was standing on the rail would be in greater danger of being killed than a person would who had on heavy-soled shoes and galoshes.

The body is not a very good conductor of electricity. The skin, especially if it is dry, offers great resistance. It requires, therefore, a high voltage to send a dangerously strong current through the body. The voltage of the ordinary dry cell, as you have been told, is about one and one half volts. This pressure is not nearly great enough to force a dangerous current through your body. You can hold the carbon post of a dry cell in one hand and the zinc post in the other without feeling the slightest shock. If you hold your tongue, which, of course, is moist, so that it touches both the carbon and zinc posts of a dry cell, you will feel a slight shock which is not unpleasant. The voltage of the ordinary house lighting circuit is about 110 volts. This voltage is high enough to send enough current through your body to give you a considerable shock. Although few people have been seriously injured by the current forced through their bodies by the pressure of the ordinary house circuit, it is not safe to assume that you will not be harmed if you make yourself a part of such a circuit. Other things being equal, the higher the voltage, the greater the danger. Probably you have seen on the poles supporting electric wires such signs as: DANGER — 10000 volts. Workmen who work on high voltage circuits either shut off the current from the wires with which they are working, or protect themselves by using insulating materials.

An account of a few accidents which have happened recently may help you understand some of the things you should avoid in order to keep from being injured by an electric current. To understand how two of these accidents happened, you must know that damp ground is a good conductor of electricity, and that, in many cases, the ground is used as the return wire in a high voltage circuit.

During a heavy sleet storm in central Illinois, many electric wires were broken. A boy in one of the small towns there saw a broken telephone wire hanging down so that it touched a puddle of water. As the wind made the wire sway to and fro, sparks came from the end of the wire. The boy told a group of his friends that he was going to take hold of the wire. His friends urged him not to, but he assured them that it was only a telephone wire and that he couldn't get hurt with that. He waded into the puddle, took hold of the wire, and was instantly killed. What he did not know was that the telephone wire was touching a high voltage wire and that the ground was a part of the high voltage circuit. When he touched the telephone wire, the current flowed from the generator through the high voltage wire, then through the telephone wire and the boy's body to the ground, and back to the generator. Of course the boy might have known from the sparks that the wire was not just a part of an ordinary telephone circuit.

A second boy was injured when he fell onto the elevated car tracks in such a way that his body was touching both the third rail and one of the rails of the track. The third rail of such a track serves as the trolley wire, and the other rails as the return wire. The boy's body became a part of the high voltage circuit, and he was badly injured.

A man was killed when he accidentally touched the terminal of the incoming electric light wire in the basement of his home. The basement floor on which he was standing was very damp. If he had been insulated from the ground, he would not have been killed. You should remember that a wire leading into your house may be in contact with a high voltage wire outside the house and that, by touching the incoming wire while you are also standing on or touching something which is a good conductor of electricity and is not insulated from the ground, you may make yourself a part of a high voltage circuit.

After reading of these accidents, you should be able to make three rules for protecting yourself from being injured by electricity. Here are two other very important rules:

Never touch any part of an electric fixture or appliance while you are in the bathtub.

Never put one hand on a gas pipe, a water pipe, or any part of a heating system while you are pulling an electric light chain with the other hand.

Many persons have been killed by touching, while they were standing or sitting in the bathtub, electric light chains, electric heaters, or some other electrical device. We can understand this when we remember that the metal pipe which drains the bathtub leads to the ground. Of course you might pull an electric light chain a hundred times while you were in the bathtub without getting any shock at all, but there is always a possibility that by doing so you may make yourself a part of a high voltage grounded circuit. The danger in holding on to gas pipes, water pipes, or heating system pipes when you pull a light chain is the same danger, since these pipes in most cases are not insulated from the ground.

A second danger from electricity is the danger from fire. In case of a short circuit, the wires through which the current is flowing become hot. If the current is strong, the wires are likely to become very hot. If anything that can burn touches these hot wires it may be set on fire. Fuses prevent fires of this sort. A fuse is a piece of metal which melts easily.

To understand how a fuse can prevent fires, let us suppose that some one who didn't understand much about electric circuits fastened the cord leading to a desk lamp to the wall by means of a loop of wire. In a lamp cord there are the two wires which lead to and from the lamp. Ordinarily these two wires are carefully insulated from each other; but we will suppose that, by rubbing against the wire loop, the insulation has been worn away so that the wire loop at last touches the wires of the cord. A short circuit is formed. The wires become hot. If there were no fuse in the circuit, the wire might become so hot that the insulation around the wires, or even the wall of the building might be set on fire. Because of the fuse, this does not happen. When there is a short circuit or when for any reason too strong a current is flowing through the circuit, the metal of the fuse becomes hot at the same time that the wires are becoming hot. The metal of the fuse soon reaches the temperature at which it melts. It melts and breaks the circuit. After the difficulty in the circuit has been found, a new fuse can be put in the circuit.

Unfortunately electric currents can cause fires in one way which the use of fuses cannot altogether guard against. When you read in the papers that a fire was caused by defective electric wiring, you may be fairly sure that the fire was caused by an "arc."

If, while a powerful electric current is flowing from the end of one wire to the end of another, the two ends of the wires are moved a very short distance apart, the ends of the wires become so hot that some of the metal is changed to vapor. This vapor forms a pathway from the end of one wire to the end of the other, and the circuit is not broken as you might expect that it would be. The vapor bridge becomes very hot as the current flows through it. This very hot vapor bridge is called an arc. Since an arc is very hot, anything burnable which touches one is likely to be set on fire.

Arcs may be formed not only between the ends of two wires but also between two wires twisted together as they are in an extension lamp cord, or between the end of a wire and the screw or binding post to which it is supposed to be attached. In fact, an arc may be formed wherever there is a poor connection in a circuit with a sufficiently high voltage. Perhaps, when you have been using an electric iron, you have heard a spluttering noise in the attachment by means of which the iron is connected to the electric lighting circuit. Perhaps you have heard a similar noise in a lamp socket. The noise is due to the fact that there is a poor connection in the attachment or the lamp socket, and an arc has been formed.

You needn't be afraid, for fear dangerous arcs will be formed, to use cells in your experiments with electricity. As you have been told, unless the voltage is high, arcs are not formed.

Fuses are not much protection against fires caused by arcs because an arc offers so much resistance that the current flowing through the circuit is not, as a rule, strong enough to make the fuse metal hot enough to melt. The arc itself is very hot, but the rest of the circuit is not.

It is to prevent accidental arcs from setting a house on fire that the electric light wires in the walls of well-wired houses are enclosed in iron pipes called conduits.

It is to prevent arcs from forming that wires which are to be joined should be soldered together, not just twisted together and wrapped with tape.

It is because of the danger that arcs may be formed between the wires of the extension cord that fire commissions advise against extension lamps.

The danger in a person's doing his own electric wiring instead of hiring an expert electrician to do it is, in part, due to the fact that he may not know enough about electric wiring to guard against the danger of electric arcs.

## XII. ELECTRONS

What is an electric current? You have been told how an electric current can be generated, how circuits for electric currents must be provided, when an electric current is dangerous and when it is not, but you have not been told what an electric current is. Perhaps, when you read about the flow of electricity through a circuit, you thought of electricity as a liquid somewhat like water. Probably you have heard electricity spoken of as "juice." You may even have been surprised to find that wires for electric connections are not hollow to enable the electricity to flow through. The slang word "juice" gives us the wrong idea of what an electric current is. There was a time when scientists believed that electricity was an invisible, weightless fluid, but that was before the electron theory had been worked out.

Scientists tell us now that an electric current is a movement of electrons through a conductor. When you close the switch of such a circuit as that shown in Figure 30, you start a movement of electrons through the circuit. The moment you open the switch and break the circuit, the electrons slow down and stop. When the switch is closed once more, the movement begins again.

But what is an electron? No scientist can give a description of an electron which he is certain is accurate, for electrons cannot be seen. Any account of the nature of electrons is a theory — an explanation, based upon the way electrons act, of what electrons are. The electron theory, as it has been very widely accepted, is this:

Electrons are very small particles of negative electricity. They are the building blocks of which all substances are in part made. All substances are built of tiny particles of matter called atoms. All atoms, in turn, are made up in part of electrons, which travel around positively charged electric particles, or nuclei, much as the planets in our solar system travel around the sun. The positively charged particles are called positive electrons or protons. Electrons are very much smaller than anything which can be seen with even the most powerful microscopes. They are much smaller than disease germs, for example, although some disease germs are so small that it would take fifty thousand of them to make a row an inch long. It would take more nearly a million million electrons to make a row of that length. It would take nearly two thousand electrons to weigh as much as the smallest particle of hydrogen, the hydrogen atom, which was supposed for a long time to be the smallest bit of matter in the universe. Positive electrons are even smaller than electrons, although they weigh more.

According to this theory, although all substances are made up in part of electrons, we do not have an electric current unless electrons are made to move from their places in atoms and travel from atom to atom in the conductor. One scientist has figured that, if the strength of a current is one ampere, more than six billion billion electrons pass any given point in the conductor in one second. Generators and cells, as you have been told, are the most important two devices for generating an electric current. This means that generators and cells are able to set these tiny particles of negative electricity to traveling through a conductor. In a circuit in which a cell is the "pump" which forces the electrons to move, the electrons travel always in one direction. In a circuit in which the current is furnished by a generator, the electrons may move always in one direction, or they may move first in one direction, then in the other. In one case we have a direct current, in the other an alternating current. In such a circuit as that shown in Figure 23, the movement of electrons outside the cell is from the zinc or negative pole to the carbon or positive pole of the cell. Before scientists had worked out this theory of electrons, they spoke of the current as flowing from the positive pole to the negative pole. Many people continue to speak of the current as flowing in this way even though they believe that the electrons really move from negative to positive.

This theory explains why a wire through which an electric current is flowing looks no different, as a rule, from a similar wire through which no current is flowing. Electrons are much too small to be seen as they move through the wire. The theory explains, too, why a wire need not be hollow in order to let electricity flow through it. There is plenty of room in even a solid substance like copper for such tiny particles to move.

Scientists who experimented with electric currents shortly after it was found that electric currents could be generated thought that current electricity was something different from static or frictional electricity. That idea was soon given up. Frictional electricity can be explained in terms of electrons just as current electricity can. When you rub a glass rod with silk, electrons are rubbed from the rod onto the piece of silk. The glass then has fewer of these little particles of negative electricity than it normally has; it has, therefore, a positive charge. The silk has a negative charge because it has more electrons than usual. When you rub a hard rubber rod with fur, the rubber rod acquires electrons from the fur. The rod, having more electrons than usual, is negatively charged, and the fur, having fewer than usual, is positively charged. In some of your experiments with frictional electricity, you may have obtained small electric sparks. This means that electrons jumped from a place where there were more electrons than usual to a place where there were fewer. You doubtless remember from reading an earlier chapter that people learned to get electric charges by friction long before they learned to generate steadily flowing currents of electricity; they learned, in other words, to make electrons jump from place to place before they learned to make them march steadily through a conductor.

Remember that what you have been told about electrons is merely a theory. This electron theory, although it has been very widely accepted, may not be right in all particulars. Recent experiments tend to show that it is not. In many laboratories experiments are now being carried on to find out more about the nature of electrons. Some scientists have come to believe that atoms are not built like solar systems, and that electrons are really some special kind of wave. One of the interesting things to watch for in the next few years will be reports of what scientists find out about the nature of electrons, and about the part electrons play as the building blocks of atoms.

# MAGNETS

## XIII. PERMANENT AND ELECTRIC MAGNETS

Probably you have played with small horseshoe magnets. If you have, you know that these magnets can pick up little objects made of iron or steel. The scientists' way of saying this is that magnets attract iron and steel.

Perhaps as you read the last paragraph you said to yourself, "My magnet will attract some things that are not made of iron or steel; I am sure that I have picked up pieces of tin with it." A magnet will pick up pieces of what we commonly call tin, but what we call tin is really, in many cases, sheet iron covered with a thin coating of tin. The magnet attracts the iron on the inside, not the tin on the outside. A magnet can act through materials which it doesn't attract at all.

You may have been puzzled when you were playing with a magnet to find that the magnet would pick up some common pins and would not pick up others. This is really not puzzling when you find that, although all common pins look much alike, some are made of brass coated with tin, and some are made of steel. You can easily sort out steel pins from brass ones by using a magnet.

Magnets do attract slightly a few substances besides iron and steel. Nickel and cobalt are two of these substances. The magnets' slight attraction for these substances is not important. Their attraction for iron and steel, on the other hand, is very important.

A magnet can be made to pick up pieces of materials which it does not attract. You must have some iron or steel, however, in order to help the magnet do this. If you try to pick up a piece of paper with a magnet, you find that the paper is not attracted at all. But if you put a little piece of iron or steel under the paper, the magnet will attract the piece of iron or steel, and will lift the paper along with the iron or steel.

Of course a magnet cannot pick up every object it attracts. If an object is made of iron or steel, the magnet will attract it, but the magnet may not be strong enough to pick it up. You should be able to feel the pull, however, when you hold your magnet against anything made of iron or steel.

If you wish one of the little horseshoe magnets to drop its load, you have to shake or pull the load away from it. Perhaps you have used iron filings in playing with your magnet. Iron filings are tiny bits of iron. They are made in iron foundries and machine shops just as sawdust is made in shops where things are built of wood. If you put your horseshoe mag-

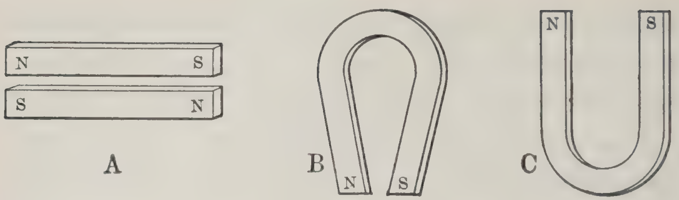


Fig. 39. Permanent Magnets of Three Shapes
*A*, bar magnets — *B*, horseshoe magnet — *C*, U-shaped magnet

net down in a pile of these filings, you will find that many filings stick to the magnet. You will find, too, that you can shake some of the filings loose from the magnet, but that the only way to get most of them off is to rub or scrape them off. The magnet continues to attract them because it is a permanent magnet. Saying that a magnet is a permanent magnet is another way of saying that it is always a magnet.

Although many permanent magnets are horseshoe shaped, they are by no means all that shape. Some are shaped like the letter U. Some are straight bars. Figure 39 shows you magnets of these three shapes. Permanent magnets are sometimes made in other shapes, too.

The ends of a magnet are called its poles. Most permanent magnets have one pole marked *N* and the other marked *S*. If a bar magnet is hung up so that it is free to turn around, and if there is no iron or steel near by and no other magnet close, one pole will point toward the north and the other toward the

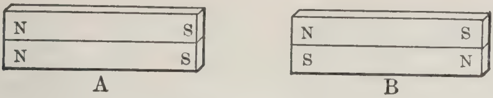


Fig. 40. Two Arrangements of Permanent Magnets

south. You can see from this why one pole is called the north pole and the other the south pole.

If you have two magnets, you will find it fun to try to pick up one magnet with the other. Suppose your magnets are bar magnets. You will find that, if they are arranged as shown in Figure 40A, you cannot lift the lower one by lifting the upper one. The upper one doesn't seem to be pulling the lower one at all. But, if you put the magnets in the position shown in Figure 40B, the upper magnet will pull the lower one and, if the magnets are strong enough, you can lift the lower one by lifting the upper one. This is not puzzling when you find how the poles of magnets act toward one another. North poles attract south poles. South poles attract north poles. South poles, however, do not attract south poles, and north poles do not attract north poles. Indeed, the north pole of a magnet actually pushes away the north pole of another magnet; and the south pole of one magnet pushes away the south pole of another magnet.

The whole story of how magnets act toward one another can be told in very few words: Opposite poles attract each other; similar poles repel each

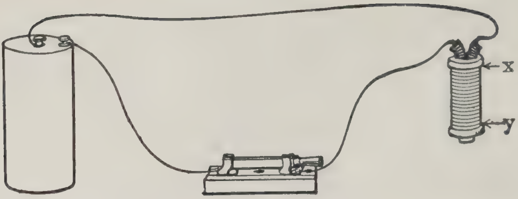


Fig. 41. An Electromagnet Circuit

other. A slightly different way of telling the story is: Unlike poles attract each other; like poles repel each other.

Occasionally you find that two magnets do not act toward each other as they should according to this rule. This happens when one of the magnets is very much stronger than the other. The very strong magnet attracts the weak one just as if it were an unmagnetized piece of steel.

Not all magnets are permanent magnets. Some are electric magnets. Electric magnets are made of iron around which insulated wire is wrapped. An electric magnet has no force except when an electric current is flowing through the wire of the magnet. Electric magnets are usually spoken of as electromagnets. Figure 41 shows an electromagnet in a circuit with a dry cell and a switch. When the switch is closed, the electricity from the cell flows through the wires of the magnet, and the electromagnet attracts iron and steel just as a permanent magnet does. When the switch is opened, the electromagnet loses its force and drops its load. It is possible to remove the magnetism from a permanent magnet by heating it red-hot, but a permanent magnet cannot be made to lose its magnetism instantly, as the electromagnet does when the circuit is broken.

An electromagnet has a north pole and a south pole just as a permanent magnet has, but, as a rule, the poles of an electromagnet are not marked. The poles of an electromagnet are not marked because which pole is which depends upon the way in which the electromagnet is connected. Let us suppose that, by testing with a permanent magnet, you find that the pole marked $x$ in Figure 41 is the north pole of the magnet. If the wire attached to the carbon post of the dry cell is now attached to the zinc post, and the wire attached to the zinc post is moved to the carbon post, the current of electricity will flow around the magnet in the opposite direction. The pole marked $x$ is now the south pole, and $y$ is the north pole. It is not nearly so easy to change the poles of a permanent magnet.

An electromagnet can be made stronger by sending a stronger current of electricity through it. If two cells are put in the circuit, the magnet should pick up about twice as heavy a load as it can lift with one cell.

Both electromagnets and permanent magnets are strongest at the poles. From this fact you should be able to see an advantage in making a magnet horseshoe or U-shaped. In magnets of these shapes, the poles can both be used at one time to pick up a load.

If you have tried to pick up small nails or tacks with a magnet, you probably have found long strings of tacks or nails hanging from the poles of the magnet. Pieces of iron or steel are magnets themselves when they are touching a magnet. As soon as they are taken away from the magnet, the pieces of iron lose their magnetism. Bits of steel may still be magnetized after they have been taken away from the magnet because steel holds magnetism very much better than soft iron. This should help you understand why permanent magnets are made of steel and electromagnets of iron.

A magnet attracts not only the iron and steel which it touches, but any iron or steel which is near by. Probably you have watched needles or iron filings jump up to a magnet when the magnet was held close to them. The stronger the magnet, the farther small bits of iron and steel can be made to jump to it. The stronger the magnet, the farther its force reaches. The region in which the force of a magnet can be felt is called the magnet's magnetic field.

If a piece of cardboard is put on top of a magnet and if iron filings are sprinkled on the cardboard, the iron filings which fall within the magnetic field of the

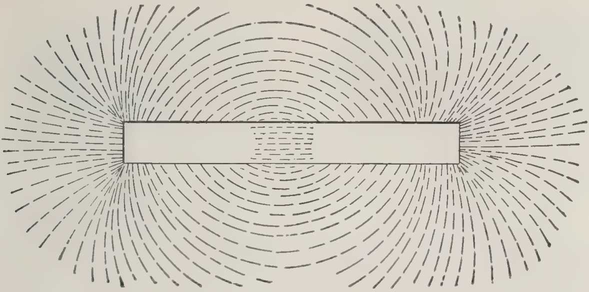


FIG. 42. THE MAGNETIC FIELD AROUND A SINGLE MAGNET

magnet are pulled into place by the magnet so that they make a design. Figure 42 shows this design. Notice that the rows of filings reach from one pole to the other. This shows that the two poles are attracting each other. Scientists call the rays of magnetism which reach from one pole of a magnet to the other "lines of force."

Figure 43 A shows the arrangement of filings around two bar magnets placed with opposite poles near each other. Figure 43 B shows how the filings arrange themselves when similar poles are close to one another. Whenever the filings are arranged in lines which reach from one pole to another, the two poles are attracting each other. They must, then, be unlike poles. If the rows of filings from one pole bend sharply away from the rows of filings from another pole, the two poles are like poles. Can you tell which poles are opposite and which ones are similar in Figures 43 C and 43 D. You should be able to.

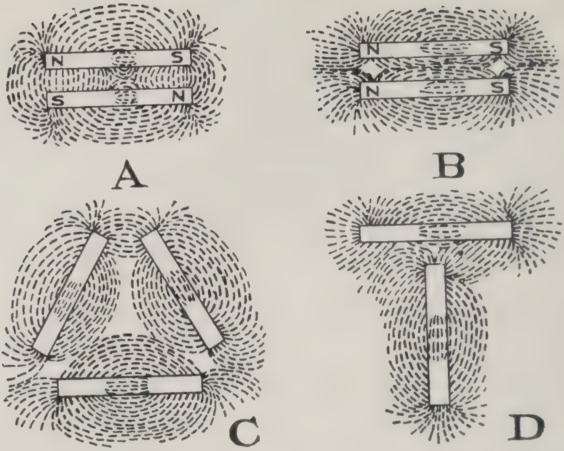


FIG. 43. MAGNETIC FIELDS AROUND COMBINATIONS OF MAGNETS

Permanent magnets were known and used long before electromagnets were invented. The first permanent magnets were found, not made. Pieces of a certain kind of iron ore are magnets without having to be magnetized. Pieces of this iron ore are often called "lodestones." Figure 44 shows two lodestones. A lodestone has poles just as all magnets do. As Figure 44 B shows, you can easily locate the poles if you dip the lodestone into iron filings. We do not know who found the first lodestone that was found, but Chinese records show us that the Chinese knew about lodestones at least three thousand years ago.

There are many stories of how magnets got their name. According to one story they were given this

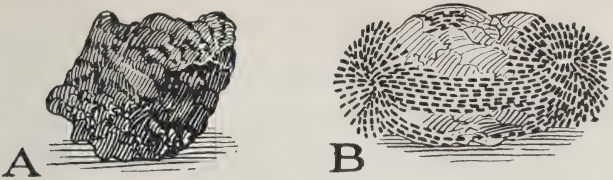


Fig. 44. Pieces of Lodestone

name because the first magnet or lodestone was found by Magnes, a Greek shepherd. The story tells that Magnes was tending his sheep on the mountain one day when he happened to rest his iron shepherd's crook against a piece of dark-colored rock. To his surprise he found it impossible to pull his crook away from the rock; the rock pulled the crook harder than he could pull it.

Another version of this story tells that it was not Magnes' crook, but the nails in his shoes, which were attracted by the lodestone.

There may possibly have been a shepherd Magnes, and he may have found lodestones, but he was certainly not the first person to find them. The Chinese knew about lodestones before the time when Magnes is supposed to have lived.

Some think that the word "magnet" comes from the Latin word "magnus," which means "big" or "heavy." Lodestone is heavy.

Still others believe that the word "magnet" comes from the old name, Magnesia, of a province of Greece. Lodestone is fairly common in that region. This explanation is probably the right one.

## XIV. EXPERIMENTS WITH MAGNETS

As a rule, scientists perform experiments to find answers to definite questions. Notice that at the beginning of each of the following sets of directions for experiments a question is asked. The experiment should answer that question for you.

1. What do permanent magnets attract?

Test as many materials as you can with a permanent magnet. List the substances which you find are attracted.

2. Do magnets act through materials which they do not attract?

Put a few iron filings on a piece of stiff cardboard. Move a magnet underneath the cardboard. Use a sheet of copper instead of the cardboard. Repeat the experiment with sheets of any other materials you can get.

3. Can magnets be made to pick up pieces of materials which they do not attract?

Try to pick up a small piece of paper with a magnet. Put a few iron filings on the table and put the small piece of paper on top of them. Try again to pick up the paper with the magnet.

4. Why is one end of a permanent magnet marked *N* and the other *S*?

Hang a permanent bar magnet up in a paper stirrup like the one shown in Figure 45. Leave the magnet until it comes to rest.

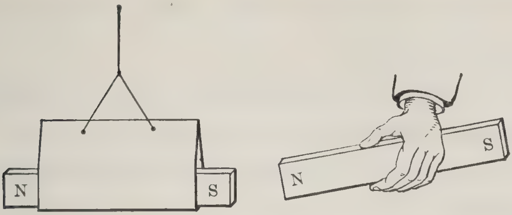


Fig. 45. Apparatus for Showing how Magnets Act toward Each Other

5. How do magnets act toward each other?

Try to pick up one magnet with another magnet of the same size and shape. If you have bar magnets, try them in the positions shown in Figure 40.

Hang a bar magnet up in a stirrup like the one shown in Figure 45. Hold the north pole of a magnet near the south pole of the suspended magnet. Hold the south pole of the magnet in your hand near the north pole of the suspended magnet. Hold the south pole of the magnet in your hand near the south pole of the suspended magnet. Hold the north pole of the magnet in your hand near the north pole of the suspended magnet.

Stand a bar magnet on end with the north pole at the top. Move toward it another bar magnet which is upright with the north pole at the top.

6. Why are electromagnets called electromagnets?

Connect an electromagnet, a cell, and a switch as shown in Figure 41. Close the switch. Try to pick up iron filings with the magnet. Open the switch.

Use the electromagnet to move the iron filings from one place to another.

7. Do electromagnets attract the same materials which permanent magnets attract?

Test the materials which you tested with a permanent magnet.

8. Do electromagnets have poles?

Suspend a permanent bar magnet in a stirrup. Hold one end of an electromagnet near one pole of the permanent magnet. Hold it near the other pole. If one end of the electromagnet attracts one pole of the permanent magnet and repels the other pole, the electromagnet has poles.

9. Can the poles of an electromagnet be changed?

Find out, by using a permanent magnet, which end of your electromagnet is the north pole. Move the wire which is attached to the carbon post of the cell to the zinc post and move the second wire from the zinc post to the carbon post. Test the end of the electromagnet which was the north pole.

10. How can an electromagnet be made stronger?

Find out how many large nails your electromagnet will pick up when there is only one cell in the circuit. Put a second cell in the circuit. Find out how many nails it will pick up now.

11. Where are magnets strongest?

Cover a permanent magnet with small nails or tacks. Lift the magnet up so that all the nails which are not being strongly attracted will fall off. Where are most of the nails which remain on the magnet?

Repeat this experiment with an electromagnet.

12. Why should electromagnets be made of iron and permanent magnets of steel?

Wrap several turns of insulated wire around a soft iron bolt. Connect the ends of the wire to a dry cell. Try to pick up iron filings with the bolt. Disconnect the wires from the cell and unwrap the wire from the bolt. Again try to pick up iron filings with the bolt.

Repeat the experiment with a steel knitting needle instead of an iron bolt.

13. How far away from a magnet does the force of the magnet extend?

Put a few iron filings on a piece of paper. Find out how near to the filings you have to bring a magnet in order to pick up the filings. Find out how far you can make a steel needle jump up to the magnet. Try this experiment with other magnets to find if the field of force of some magnets extends farther than that of others.

14. How can the magnetic field around a magnet be shown?

Lay a permanent bar magnet flat on a table. Cover it with a sheet of stiff cardboard, light in color. Sprinkle fine iron filings on the cardboard. Tap the cardboard very gently. Notice the pattern made by the iron filings.

Place two bar magnets side by side with opposite poles near each other. Cover with cardboard, and sprinkle on the iron filings as before. The pattern shows you that the opposite poles are attracting each other.

Repeat the experiment with similar poles near each other. In the same way, study the lines of force around an electromagnet, a horseshoe permanent magnet, and a U-shaped magnet.

Arrange three bar magnets in a triangle and show the lines of force with filings. Try other arrangements of magnets.

## XV. COMPASSES

Most of the great voyages of discovery were made after the twelfth century. Before that time sailors, as a rule, were afraid to venture far from land. They were afraid because they had no way of guiding their vessels. Of course when the sky was clear they could tell by the sun and the stars in what direction they were going, but on cloudy days and especially on cloudy nights they had no way of telling directions accurately. Late in the thirteenth century, ships on the Mediterranean began to use compasses. When the sailors found how useful compasses were, longer voyages were planned and made. Without a compass Columbus probably never would have been able to persuade any sailors to set out with him to find a shorter route to the Indies. Without a compass Magellan would not have dared undertake his voyage around the world. Do you think that Sir Francis Drake, or Vasco da Gama, or the Cabots would have planned their great voyages of discovery if there had been no compasses? Probably not.

The compass is, without doubt, the most important use of the permanent magnet. A magnetic compass is merely a permanent magnet suspended in such a way that it is free to turn. As you have been told, a magnet free to turn points north and south.

The first compasses are thought by some scientists to have been made in China. The Chinese may possibly have used them to guide their travels. But, so far as we know, there is no authentic record of their being used by sailors until they were used on the Mediterranean in the thirteenth century. In the city of Naples there is a monument to Flavio Gioja. The inscription on this monument tells that Gioja invented the compass in 1302. Gioja did improve the compass and deserves to be honored, but he did not invent it.

Compasses may have been used before any one knew how to make permanent magnets of steel. At any rate, lodestones were used in some of the early compasses. Figure 46 shows you a lodestone compass. The lodestone in such a compass could turn

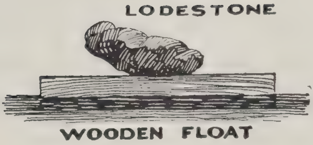


Fig. 46. A Lodestone Compass

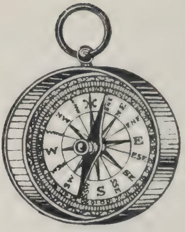


Fig. 47. A Pocket Compass

freely because the piece of wood on which it rested was floating on water. The lodestone would turn until one pole was pointing north, the other south. Of course, if you know which direction is north, you can tell the other directions.

An ordinary pocket compass, such as the one shown in Figure 47, contains a small magnetized steel needle. The needle rests on a support so that it can turn very easily. The card below the needle, as you see, is marked with directions. You will find by experimenting that you can turn such a compass around slowly without moving the needle from its north-south position.

Some people are surprised to find that the north pole of the needle does not always point to the sign for north on the dial. If it did, the compass would be useless, for the compass can be held with the sign for north in any direction. If you wish to use a pocket compass merely to tell the general direction in which you are going, you should turn the compass until the sign for north is under the north pole of the compass needle. You can then read the other directions easily.

The compass points north and south because the earth itself acts as a huge magnet with north and south magnetic poles. The earth can act through the glass and brass of the compass case and can pull the needle into its north-south position.

A pocket compass can be used to tell direction if there is no iron or steel near by, and no other magnet close. A few years ago a company of geographers went to Brazil to make some maps. They took compasses with them, for of course one must know directions very accurately in order to make an accurate map. They soon found that their compasses were of no use. There is so much iron ore in that part of Brazil that their compass needles were attracted by it and could not be depended upon at all. The north star could not be seen from that part of Brazil. Directions had to be found from the position of the sun. This is no easy matter since the position of the sun in the sky changes from day to day. These geographers realized more than ever before how much compasses help us in telling direction accurately.

A mariner's compass is very much more complicated than an ordinary pocket compass. As you can see from the picture in Figure 48, the points of the compass are marked on a round card. This

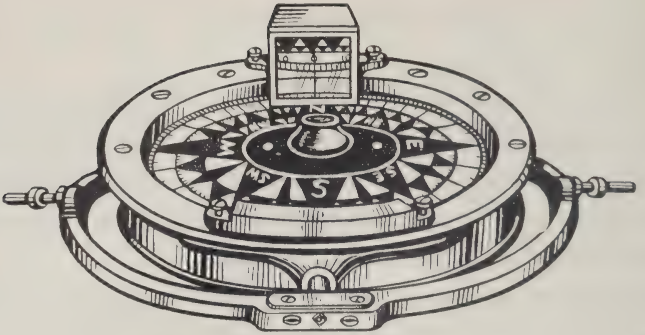


Fig. 48. A Mariner's Compass

card may be made of paper or of mica. On the under side of it several magnetized needles are fastened. Thirty-two directions are marked on the card. All seamen are supposed to be able to name the thirty-two points of the compass. Naming these points in order is called "boxing the compass." Perhaps, if you have taken a voyage on the lakes or the ocean, you have learned to box the compass yourself. The thirty-two directions are

N
N by E
NNE
NE by N
NE
NE by E
ENE
E by N
E
E by S
ESE
SE by E
SE
SE by S
SSE
S by E
S
S by W
SSW
SW by S
SW
SW by W
WSW
W by S
W
W by N
WNW
NW by W
NW
NW by N
NNW
N by W

The circular edge of the compass card is also divided into 360 divisions which are called degrees.

Since, in the mariner's compass, the needles are fastened to the card, the card turns when the needles do. In most cases the card has a little cup of agate in the center. This cup of agate rests on the point of a vertical needle. In some cases the card floats on a liquid. Notice the black line on the inside of the compass box. This line is directly in line with the keel of the vessel. Suppose the helmsman knows that, to get to his destination, he must go in the direction which is marked on his compass eight degrees east of due north. He turns the ship until the eight degree mark on the compass card is exactly in line with the mark on the compass box.

The case of a mariner's compass is made of copper. It is fastened by supports in such a way that the compass remains level even when the boat lurches.

Using such a compass is by no means an easy matter. If the north pole of a compass needle always pointed due north, and if no iron or steel were used in building a ship, reading a compass would be easy. But the north pole of a compass needle does not always point due north. Due north means toward the north geographic pole. The compass needle points to the magnetic pole, which is many miles from the north geographic pole. Moreover, practically all modern ships are made in part of iron or steel.

When Columbus sailed from Spain, no one knew where the magnetic poles of the earth were. No one even knew why the compass needle should point north. They knew that the compass needle does not always point due north, but no one knew why. It points so nearly due north in southern Europe that no one was very much excited about its failure to point exactly north. When Columbus was in mid-ocean, some of his sailors discovered that the compass was not pointing the same number of degrees west of north as in Europe. The sailors were much alarmed. They thought that they were getting into a strange region where their compasses were bewitched and were no longer good guides. Columbus did not know the true explanation, but he gave an explanation which convinced the sailors that the compasses were not bewitched.

We know now that one magnetic pole of the earth is near Hudson Bay. Its location is shown by the cross on the map in Figure 49. The other magnetic pole is far to the south in the Antarctic region. As long ago as 1590, Dr. Gilbert, the English scientist who studied frictional electricity, discovered that the earth acts as a huge magnet which has magnetic poles; but not until 1833 was the exact position of the magnetic pole near Hudson Bay known. Its position was discovered in that year by Sir James Clark Ross. The magnetic pole in the Antarctic region was located by Shackleton in his Antarctic expedition of 1908–09.

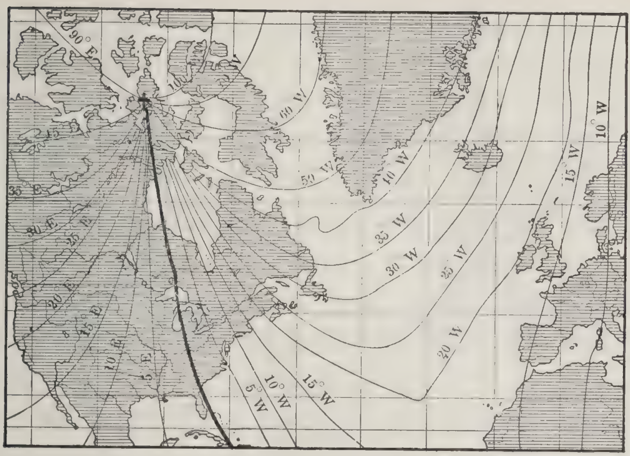


Fig. 49. Map Showing Magnetic Declination

You remember that opposite poles attract each other and that similar poles repel each other. Since the magnetic pole near Hudson Bay attracts the north pole of the compass needle, it is really the earth's *south* magnetic pole. Since it is near the north geographic pole, however, it is often called the earth's north magnetic pole.

You can tell something about how far you are from the magnetic poles by using the kind of compass called a dipping needle. If you were exactly at the magnetic pole near Hudson Bay, the north pole of your compass needle would point straight down as in Figure 50 A. If you were exactly at the magnetic pole in the Antarctic region, the south pole of your compass needle would point down. At the mag-

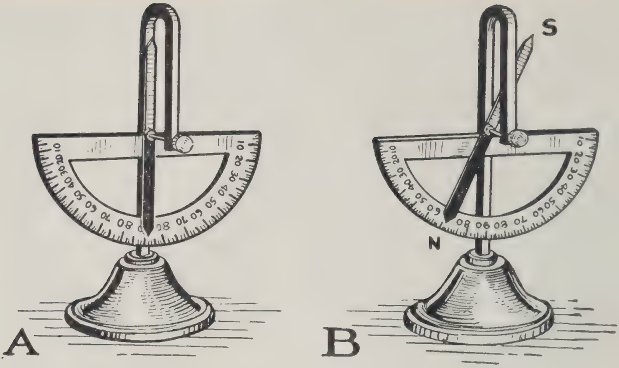


FIG. 50. A DIPPING NEEDLE

*A*, pointing as it would at the south magnetic pole — *B*, pointing as it does in Chicago

netic equator, if the compass were placed in a north-south position, the needle would be horizontal. In Chicago, the needle rests in the position shown in 50 B. This shows that we are much nearer to the magnetic pole in the north than we are to the one in the Antarctic region.

If you were to follow a pocket compass needle to the north, you would reach the magnetic pole near Hudson Bay. As soon as you passed it, the compass needle would turn round and would continue to point to the magnetic pole. You could not tell by using your compass when you had reached the north geographic pole. In some places on the earth the compass needle points east and west instead of north and south. Do you see why?

There are places on the earth where the compass needle does point due north. It points almost exactly north in Chicago. In eastern United States it points somewhat west of north. In western United States it points somewhat east of north.

The magnetic map in Figure 49 tells you how far from due north the compass points at different places on the earth. At every place on the heavy black line, the compass points due north unless other magnets or iron interfere with it. At every place on the line marked 5 degrees west, the compass needle points 5 degrees west of true north.

If you wished to use a compass for telling your directions accurately on short trips, you could find from a map like the one in Figure 49 how many degrees from true north the compass points in the region where you are. Every time you looked at your compass you could correct your reading. Suppose, for example, that you are in New York and that you wish to go due north. Since, as the map shows you, the compass points 10 degrees west of due north there, you should go 10 degrees east of the direction in which the compass needle is pointing.

The mariner has a harder time making the corrections in his compass readings. Suppose he starts from New York for Liverpool. In New York his compass points 10 degrees west of north. By the time he reaches mid ocean, as you see from the map, his compass points 25 degrees west of north.

When he reaches Liverpool his compass points only 15 degrees west of north. You see that he cannot make the same correction every time he consults his compass. He must know exactly where he is on his journey in order to know how much of a correction he has to make. More than one shipwreck has occurred because the right correction was not made in the compass reading.

Reading a compass accurately is made even more difficult by the amount of iron and steel in a ship. During the building of a ship the steel used in it is likely to become permanently magnetized. At any rate the iron and steel attract the compass needles. Various devices are used to prevent the compass needles from being greatly affected by the iron and steel in the ship.

Many naval vessels, on which there is always much iron and steel, are now using gyroscope compasses instead of magnetic compasses. Gyroscope compasses have nothing to do with magnetism. They are not entirely satisfactory, but, when we see the difficulties in reading magnetic compasses, it is not hard to understand why in some cases gyroscopes are used instead.

## XVI. EASILY MADE MAGNETIC TOYS

### An Electromagnet Set

The electromagnet set consists of an electromagnet and a switch.

For the electromagnet itself you need the following materials:

A soft iron machine bolt $2\frac{1}{2}$ inches long with nut
Ten yards of No. 24 double-cotton-covered copper magnet wire
A small piece of paper
A gummed label

Wrap a layer of paper around the bolt. Hold the paper in place with the gummed label. You wish the electricity to flow around the iron core, not through it, and the paper supplies insulation in addition to the insulation on the wire. It also makes it possible to wind the magnet more smoothly.

Begin winding at the nut end of the bolt. There is an important reason for this: If the wire should break, as it may do after the magnet has been used many times, the break is likely to come where the winding begins. If you begin winding at the nut end of the bolt, the nut can be unscrewed in case of a break there, and the break can be easily mended by splicing on a piece of wire. If the winding is begun at the head of the bolt, there may be no way of mending a break without removing all the wire.

In winding the wire on the bolt, leave about a foot of wire for connections. Wrap the wire around the bolt once. Then twist it as shown in the diagram in Figure 51A so that it will not slip. Roll up, in

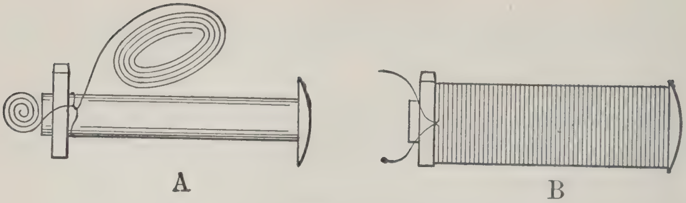


FIG. 51. A HOMEMADE ELECTROMAGNET
*A*, the beginning — *B*, the finished magnet

the way shown in the diagram, the foot of wire you have saved for connections. It will then be out of your way. Start winding the wire around the bolt. Keep pushing the turns of wire together. The more neatly you wind the wire on the bolt, the more wire you will be able to put on, and the stronger your magnet will be. Continue to wind until you have four layers on the bolt. Four is a convenient number of layers because the last layer then ends at the nut end of the bolt where you began. Twist the two ends of the wire together to keep the wire from unwinding. Your finished magnet should look like the one shown in Figure 51 B.

You could use heavier wire for your magnet, but using your magnet would then wear out your cell more rapidly than if you use No. 24 wire. You may use a larger or a smaller bolt if you wish. The amount of wire needed depends upon the size of the bolt.

There are many ways of making a switch for use with your electromagnet. Diagram 52 shows a sat-

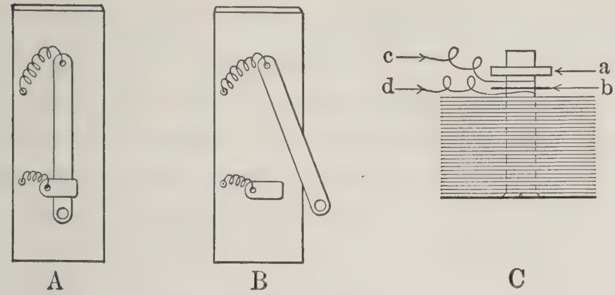


FIG. 52. A HOMEMADE SWITCH

*A*, switch closed — *B*, switch open — *C*, binding post — *a*, nut — *b*, brass washer — *c*, wire leading out from switch — *d*, wire leading to arm of switch

isfactory homemade switch. For making this switch you need:

A block of wood 2½ inches by 5 inches by three quarters of an inch
A strip of brass or copper or tin three quarters of an inch by 2½ inches and rounded at each end
A strip of brass or copper or tin three quarters of an inch by 3½ inches and rounded at each end
Two flat-headed stove bolts one eighth of an inch in diameter and 1½ inches long
Two brass washers to fit bolts
Three brass-headed upholstery nails
One wooden peg to serve as a handle for the arm of the switch
Two short pieces of No. 24 insulated copper wire

The diagram in Figure 52 C shows a detailed plan for one of the binding posts. A hole is drilled through the block of wood, and the bolt is put in from below. A brass washer is put around the end of the bolt which reaches above the wooden base. The end of the wire which reaches from the arm of the switch is wrapped around the bolt under the washer. The end of the wire from the magnet or cell is put between the washer and the nut. The nut can then be screwed down, and a good connection can be made. The washers prevent the wires of the switch from being loosened when wires from the cell and magnet are disconnected from the binding posts. Be sure that the insulation is removed from the ends of all wires used. The two wires in the switch should not be pulled tight. Wrapping each wire around a pencil will coil the wire in such a way that the appearance of your switch will not be harmed by having the wires left with plenty of play in them.

Fasten the wooden peg which is to serve as a handle to the arm of the switch before you fasten the arm of the switch to the wooden base. The longer strip of metal is to be the arm of the switch. Punch a small hole near one end of it. Then drive one of the brass upholstery nails through the hole and into the wooden peg. You may then punch a hole near the other end of the strip and fasten the strip to the wooden base with a brass upholstery nail.

The other strip of metal is folded in the middle and fastened to the base as shown in the diagram.

The folded edge is smooth, and the arm of the switch can be slipped under it easily.

In case you wish to use a wet cell to furnish the current of electricity needed, you can make a cell like that shown in Figure 6. Probably you will prefer to use a dry cell, since a dry cell can be moved from place to place safely and easily.

### PERMANENT MAGNET TOYS

The magnetic boat and the compass described on the following pages are made in part of permanent magnets. In order to make them you need to know how to make a permanent magnet. For a permanent magnet you need a piece of steel. As a rule, the harder the steel, the longer it will keep its magnetism.

There are a number of ways of magnetizing a piece of steel. If you pound the piece of steel while you are holding it so that it points to the magnetic pole to the north of us, it will become magnetized. This explains why steel ships which are in a north-south position while they are being built become permanent magnets. If you wish to magnetize a piece of steel in this way you should hold it so that the north pointing end is somewhat lower than the other end.

However, there are easier and better ways of magnetizing a piece of steel. If you rub the steel with one pole of a permanent magnet, it will become magnetized. Hold the piece of steel flat on a table.

Move the pole of your magnet along the steel from one end to the other. Then lift the magnet back to the end at which you started, and draw it once more the full length of the piece of steel. Repeat this twenty or more times. If you should rub it back and forth instead of rubbing it always in the same direction, your piece of steel will not be magnetized nearly so well.

If you rub the piece of steel with the north pole of your permanent magnet, the end of the piece of steel at which you begin to rub will become the north pole of your new magnet.

It doesn't make any difference with which pole you rub the piece of steel, but you should notice with which pole you are rubbing it. In case your new magnet is not strong enough, you should rub the piece of steel again with the same pole in the same direction, or with the opposite pole in the opposite direction.

You may magnetize the piece of steel by rubbing it with one pole of an electromagnet. The same rule about rubbing with one pole in one direction holds if you are using an electromagnet instead of a permanent one.

There is still another simple way of making a permanent magnet. This is a good way in case you do not have either an electromagnet or a permanent magnet. Roll a hundred or more turns of No. 24 insulated wire around a pencil loosely. Then pull out the pencil. Connect the coil you have made to a cell and a switch. Slip the piece of steel you wish to magnetize into the coil. Close the switch and allow the current to flow through the coil for about a minute. Then remove the piece of steel and test it. It should be well magnetized.

There are several ways of testing a piece of steel to find out whether or not it has become magnetized. One way is to try to pick up small bits of iron or steel with it. Of course, if it is not magnetized, it will not pick up iron or steel.

Another way is to test it with a permanent or an electric magnet. If one pole of the magnet attracts one end of the piece of steel and *repels* the other, the steel is magnetized. The mere fact that the magnet attracts the end of the piece of steel near which you hold it is no proof that the steel is magnetized.

If you have a compass you can use it in testing to see whether or not the piece of steel is magnetized. If one end of the piece of steel attracts one pole of the compass needle, and the other end attracts the other pole of the compass needle, the steel is a magnet.

### MAGNETIC BOAT

For making a magnetic boat you need

A large darning needle
A flat cork (specie cork) 1½ inches in diameter
White and colored paper
Paraffin

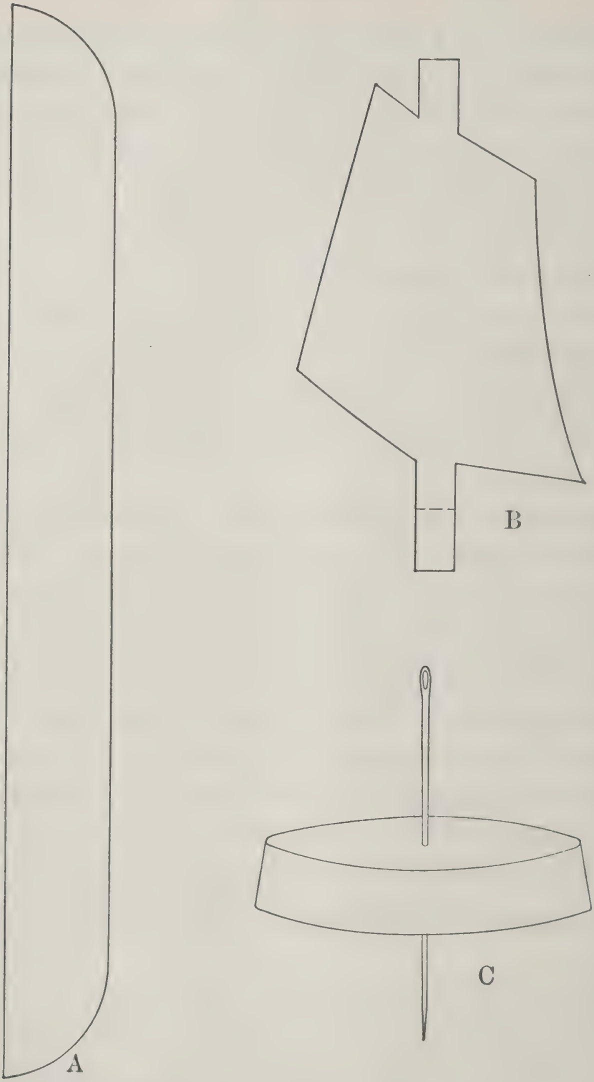


Fig. 53. Parts of Magnetic Boat

*A*, pattern for the hull — *B*, pattern for the sail — *C*, magnetized needle and cork

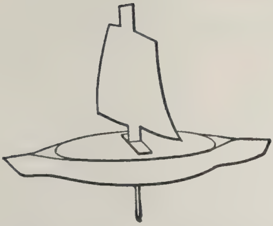


FIG. 54. A COMPLETED BOAT

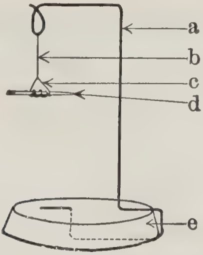


FIG. 55. A HOMEMADE COMPASS
*a*, heavy copper wire — *b*, silk thread — *c*, fine copper wire — *d*, needle — *e*, cork

Magnetize the darning needle. Push it through the cork so that about half an inch of it projects below the cork as in Figure 53 C. Cut two strips of colored paper the size and shape of the diagram in Figure 53 A. Out of white paper cut two sails the size and shape of the pattern in Figure 53 B. Hold the two sails together and fold outward in opposite directions the two flaps marked by the dotted lines. Paste the two sails together and slip them over the needle. Paste the flaps to the cork. Paste the middle of one strip of colored paper to one side of the cork, and the middle of the other strip to the opposite side, and paste the two strips of paper together at the ends. Allow the paste to dry. Then waterproof the boat by dipping it into melted paraffin. When dipping the boat into the paraffin, you will find it convenient to hold the boat by means of the part of the needle which projects below the cork. The finished boat, shown in Figure 54, will float, and you should be able to pull it about on the surface of the water with one pole of a magnet, and chase it with the other.

## A Compass

The important points to remember in making a compass are that the needle must be free to turn, and that no iron or steel should be used in making a support for the needle. Figure 55 shows one satisfactory plan for making a compass. The following materials are needed for this compass:

Nine inches No. 18 bare copper wire
Three inches No. 30 bare copper wire
A specie cork $1\frac{1}{2}$ inches in diameter
A sewing needle
A bit of silk thread

Punch a hole through the center of the cork. Put the heavy copper wire through the hole and bend it to form the support. The arm of the support should be long enough so that the needle does not hit the wire as it turns around. Magnetize the needle. Wrap two or three turns of the fine copper wire around the needle and twist the ends of the wire together to form a loop. Tie the needle to the support by means of the silk thread. Be sure to use a single, not a double, thread. The finer your silk thread, the more easily your needle will be able to turn.

## XVII. THE WONDERS OF THE ELECTROMAGNET

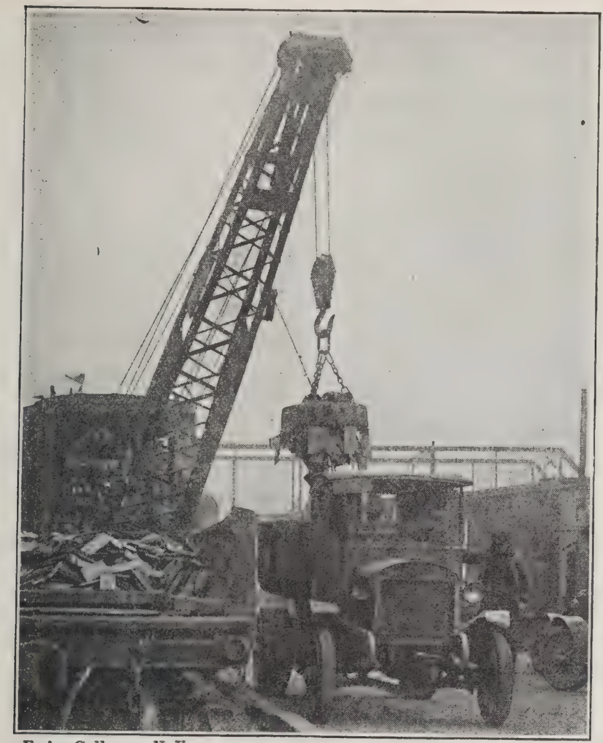
About twenty-five years ago there was a great explosion in one of the big flour mills near Minneapolis. A spark ignited the flour dust in the air of the mill, and the dust exploded almost as violently as gunpowder would have. Much damage was done. The spark was caused by a bit of iron which had been caught between two of the great grinding disks. As the disks turned round, the bit of iron had been rubbed until it had become white hot. The explosion followed. It was not the first explosion of the kind nor the last, but now we do not hear of such explosions. There are none. In the wheat there are still bits of iron which have been broken from the threshing machinery, but they no longer cause explosions. Electromagnets are now built into the wheat cleaning machines so that the wheat passes over these magnets before it reaches the grinding machines. The magnets are strong enough to pull all the bits of iron from the wheat. At the end of the day the bits of iron are removed from the magnets, and the magnets are ready for another day's work.

The prevention of explosions in flour mills is just one of the wonders which the electromagnet is able to perform. The electromagnet is now very much more important than the permanent magnet. It can be used for many more purposes than the permanent magnet can. As you read on, you will see that there are three reasons for this.

An English scientist once tried to find out how heavy a load he could lift with permanent magnets. He was able to combine several permanent magnets in such a way that they could lift a weight of one hundred pounds. Perhaps stronger permanent magnets than those he used have been made, but certainly no permanent magnet or group of permanent magnets has ever been able to lift so much as a powerful electromagnet can lift. Electromagnets powerful enough to lift a load weighing twenty thousand pounds are not uncommon now. Of course the current for these big electromagnets is furnished by generators, not by cells.

A very strong electromagnet was once made out of a cannon. Some soldiers wrapped more than five thousand turns of wire around a huge fifteen-ton cannon. Then they sent a current of electricity through the wire, and the cannon became a magnet. It was strong enough to hold many two-hundred-fifty-pound cannon balls. It was so strong that when a man stood in front of it iron spikes could be made to stick to his forehead. It took six men with a block and tackle to pull away a piece of iron attracted by this magnet. This magnet, of course, was not useful except for experiments.

At first thought it might seem that a magnet

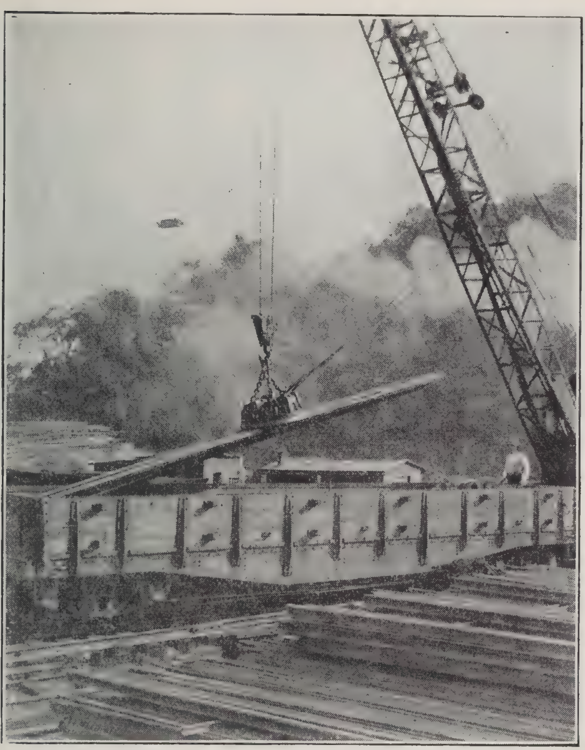


*Ewing Galloway, N. Y.*

FIG. 56. USING AN ELECTROMAGNET TO UNLOAD SCRAP IRON

which loses its magnetism would be less useful than one which keeps its magnetism. But it works the other way round. Figure 56 shows an electromagnet being used in unloading scrap iron from a car. It can lift hundreds of pounds of iron at one time. After it picks up its load, the crane moves it to the place where the load is to be dropped. Suppose for a moment that it is a permanent magnet instead of an electromagnet. When the crane moves it to the place where it is to drop its load, how can it be made to drop it? It is possible to make a permanent magnet lose its magnetism, but the magnet must be heated red-hot and pounded in order to make it lose its magnetism quickly. Of course the load could be pulled off, but that would probably take more time and more men than if men instead of the magnet were used to unload the iron from the car. Since an electromagnet is used, what does happen is that the operator merely opens the switch and the electromagnet drops its load. As you read of the different ways in which the electromagnet is used, ask yourself this question: Could a permanent magnet do this work as well as an electromagnet?

You have been told that the strength of an electromagnet depends partly upon the strength of the current flowing through it. If a permanent magnet is able to lift ten big nails to-day, it should be able to lift ten big nails to-morrow. Of course you can heat the magnet and make it lose some of its magnetism. You could, for example, make it so weak that it would lift only one nail. But if you wished to make it strong again you would have to remagnetize it in one of the ways mentioned on page 117. How different it is with an electromagnet! Figure 57 shows an electromagnet being used in loading a car with steel rails. If the operator wishes to lift one rail, he sends

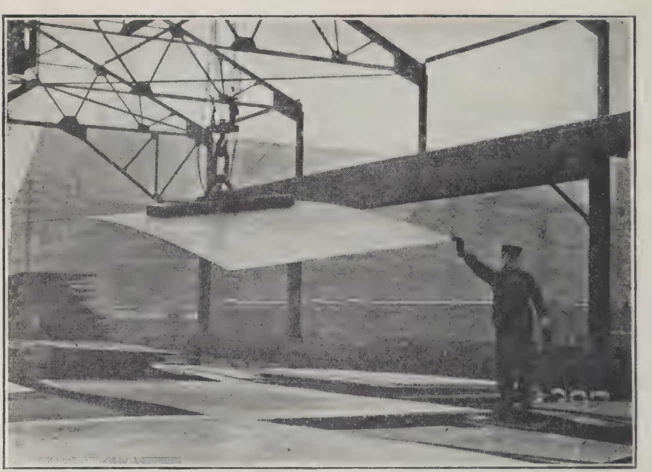


*Ewing Galloway, N.Y.*

FIG. 57. USING AN ELECTROMAGNET TO LOAD STEEL RAILS

a current of a certain strength through the coils of wire of the magnet. If he wishes to lift three rails at once, he merely increases the strength of the current.

A trip through the mills and factories of a big city should show you the electromagnet doing many different kinds of work. In an iron foundry you might see a magnet being used to lift a skull-cracker. A skull-cracker is a huge pear-shaped iron weight. It



*Ewing Galloway, N.Y.*

Fig. 58. Using an Electromagnet to Move Sheets of Steel

is used for breaking up scrap iron into pieces small enough to be put in the furnace. A magnet attached to a crane is used to lift the skull-cracker high above the pile of scrap iron. The circuit is then broken, and the magnet drops the skull-cracker. It falls with great force into the heap of scrap metal.

In a junk yard you might see an electromagnet being used to separate scrap iron and steel from scraps of other metals. Sorting scrap metal by hand is a long and tedious process. It is not always easy to tell what kind of metal a piece of scrap metal is, for the metal is, in many cases, painted or discolored. The electromagnet attracts iron and steel even if it is rusty or painted.

In a rolling mill you might see an electromagnet being used to lift a large thin sheet of steel, as in Figure 58.

In a steel mill you might find some magnets unloading pig iron and others lifting hot blocks of steel. It makes no difference to the electromagnet whether its load is hot or cold.

In a factory where farm machinery is made, you might find electromagnets being used to unload barrels of nails from a car or to move pieces of machinery from place to place.

When you reached a factory where safes were being made, you might be just in time to see an electromagnet lifting a heavy safe several stories above a concrete floor. The current is switched off and the safe is dropped. If the safe escapes unharmed, the manufacturers know that, in a fire, the safe could fall many stories without being injured.

Using these huge lifting magnets has meant saving time and reducing the number of men needed for such heavy work. A trial was once made to see how much time using a lifting magnet did save. A wagon which it took two men four hours to load was unloaded by one man with an electromagnet in two and a half minutes. In another trial one man was able, by means of an electromagnet attached to a derrick, to unload one hundred nine thousand tons of pig iron in two hours and five minutes.

Using electromagnets has made work in many mills and factories safer, too. Before electromagnets were used, very heavy weights had to be lifted by means of chains. Adjusting these chains was not dangerous if the load to be lifted was cold, but often workmen were injured in attempting to fasten chains around hot blocks of steel. Now the workmen do not have to go near the steel in order to move it with an electromagnet.

When electromagnets were first made and used for lifting heavy loads, many people feared that the electric current would fail and the electromagnet would drop its load and injure many workmen. Of course, if the generator should stop working for only a second, or if a short circuit should occur in the wiring, the magnet would drop its load. Neither of these happens often. They do not happen any oftener than chains used to slip or break and let the load fall. Of course workmen should stay from underneath a magnet lifting a heavy load.

You should remember that these magnets alone can lift nothing far. They attract the iron and steel, but they must be lifted and moved from place to place by means of derricks or cranes.

These big lifting magnets are of various sizes and shapes. Some of them weigh more than a thousand pounds. However, one of these magnets can lift a load which weighs much more than the magnet itself weighs. The shape of the magnet depends upon what use is to be made of it. Figure 56 shows a magnet of a very common shape. You cannot see the coils of wire because they are surrounded by an iron case. Notice that the magnet shown in Figure 58 is of a different shape. Some of the early lifting magnets were horseshoe shaped, but other shapes are now more popular.

Using electromagnets for lifting great loads of iron and steel is by no means the only use of the electromagnet. In factories where needles are made, electromagnets are used to gather up the bits of steel at the end of a day's work. Before the time of the electromagnet, these bits of steel were swept out with the dirt and were wasted.

Other magnets are used in getting iron from certain kinds of low-grade iron ore. The iron ore is crushed by machinery. Then electromagnets take out the bits of iron from the crushed rock. It is so expensive to take the iron from this low-grade ore in the usual way that, before electromagnets were used, most such low-grade ore was thrown away.

In factories where rice chaff is ground to make cattle food, electromagnets are used to pull any bits of iron from the chaff before it enters the grinding machines. Fires in these mills are prevented just as explosions are prevented in flour mills.

Magicians find electromagnets very helpful in doing some of their tricks. A famous French magician, Houdin, tells of how he used an electromagnet in one of his performances. This performance was given in North Africa. The audience was made up of Arabs. An iron chest stood in the center of the platform. The magician announced that he could make a strong man lose his strength. He then asked one of the Arabs near by to lift the chest. The Arab did it easily. The magician then waved his wand over the Arab and said that the Arab would now find himself weaker than a woman. The magician told the Arab to lift the chest again. The Arab of course didn't feel any weaker, and he stepped forward to lift the chest again as if to say, "This trick is certainly no trick at all." He pulled at the chest. The chest didn't move. He pulled harder. Still the chest didn't move. Should he let these friends of his see that he really had become weaker than a woman? Certainly not. He braced himself and pulled so hard that it looked as if he would pull the chest to pieces. But he couldn't lift it from the floor at all. He was so angry that he wrapped his robes about him and rushed from the hall.

Probably you can guess what had happened. The chest was resting on the poles of a very powerful electromagnet. At first the switch was open, and the Arab lifted the chest easily. Then the magician's assistant closed the switch. The electromagnet attracted the iron of the chest with so much force that the Arab hadn't enough strength to pull it away. This trick of the "light and heavy chest" is only one of the many tricks in which magicians use electromagnets.

Small electromagnets are used by doctors in removing bits of iron or steel from people's bodies. Removing iron or steel particles from the eye with a magnet is common. Frequently bits of iron have been removed from the lungs. During the war electromagnets were found to be very helpful in removing bits of iron and steel from wounds.

If this were the whole story of the uses of the electromagnet, the electromagnet even then would rank as a great invention. However, these instances of the use of the simple electromagnet tell only a small part of the story of the importance of the electromagnet. The electromagnet is a part of many pieces of electrical apparatus. Figure 59 shows two of them. The telegraph sounder contains an electromagnet. Telegraph relays contain electromagnets, too. Door bells, telephone receivers, radio loud-speakers, headphones, and spark coils contain them. Transformers are made in part of electromagnets. Every motor contains at least one electromagnet. As you were told in an earlier chapter, every large generator has an electromagnet in it. And so it goes. If you have any idea of the importance of radio, the telephone, the telegraph, the motor, and the generator,

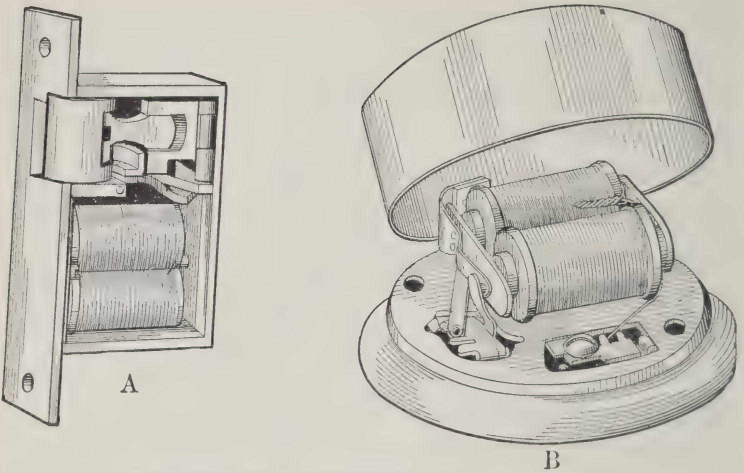


Fig. 59. Two Devices Containing Electromagnets
*A*, door opener — *B*, buzzer

you will not wonder that the invention of the electromagnet has been called one of the most important steps in the history of electricity.

## XVIII. HOW AN ELECTROMAGNET MAKES A BELL RING

You have been told that electromagnets are used in electric bells. Perhaps you have never seen an electromagnet in a bell. Usually the magnets are covered. Figure 60 shows two electric bells. The diagrams show the bells with the covers removed so that the U-shaped magnet in each can be seen.

The single stroke bell is the simpler of the two.

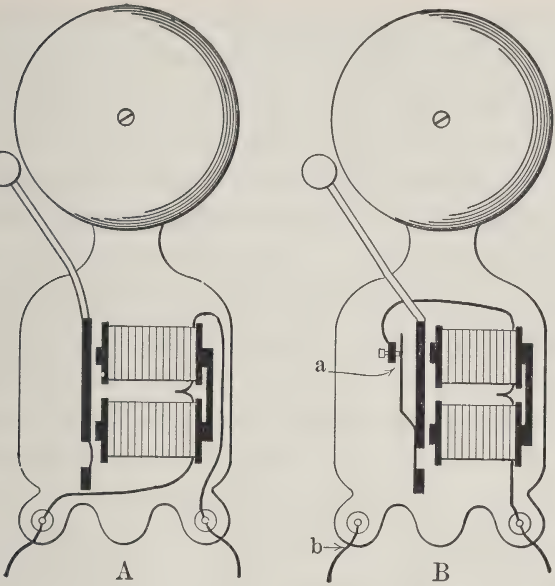


FIG. 60. ELECTRIC BELLS
*A*, a single stroke bell — *B*, a multiple stroke bell

Let us see how the electromagnet can make such a bell ring. When the push-button is pressed, the current flows through the electromagnet. The magnet pulls toward it the iron armature to which the clapper is attached. The clapper strikes the bell. As soon as the push-button is released, the circuit is broken, the magnet loses its magnetism, and the armature leaves the magnet. The clapper does not strike the bell again unless the push-button is pressed again.

In an ordinary bell, such as the one shown in Figure 60 B, the clapper strikes the bell again and again when the push-button is held down. To understand why this is true, you must know the path of the current through the bell. The diagram shows the narrow strip of brass which is fastened to the armature. Notice that this brass spring is bent so that it touches the contact point (*a*). When the bell is connected with the cell and push-button, and the push-button is pressed down, the electricity has a complete path through the bell. It has a path from the binding post to the electromagnet, through the electromagnet to the contact point, through the spring, and then through the metal of the base of the bell itself to the second binding post. As soon as the magnet is magnetized, the armature and clapper are pulled over. The clapper strikes the bell. But also when the armature is pulled over, the spring is pulled away from the contact point. When this happens, the circuit is broken, and the magnet loses its magnetism. The armature then flies back away from the magnet. Once more the current flows, because once more the spring touches the contact point. Again the magnet is magnetized, and again the clapper is pulled over so that it strikes the bell. Again the circuit is broken, and the armature flies back. Once more the circuit is complete, the magnet is magnetized, and the clapper strikes the bell. Once more the circuit is broken, the magnet loses its magnetism, and the armature flies back. So it goes on as long as the push-button is held down. Of course, the making and breaking of the circuit takes place much more rapidly than you can read about it.

The bell shown in Figure 60 B can be made into a one stroke bell by connecting the wire (*b*) to the contact screw instead of to the binding post. Do you see that this cuts the spring out of the circuit so that the bell works just as the bell in Figure 60 A works?

# USING ELECTRICITY TO PRODUCE HEAT AND LIGHT

## XIX. TURNING NIGHT INTO DAY WITH ELECTRICITY

Did you ever stop to think how much shorter your day for work and play would be if there were no artificial light? Suppose we had to depend entirely upon sunlight. If we lived in northern United States, we should have to get all our working and playing done in nine hours on some winter days. We should have even fewer hours of light on those days if it were cloudy. In summer time, of course, we should have a longer day, but it would be very hard for us to get all our working and playing done while the sun shone. With artificial light we have succeeded in stealing some of the hours of the night for working and playing. Some people even work by night and sleep by day. Probably, when ways of making fire were first discovered, people considered the light the fire gave just as important as the heat. Gradually better and better ways of turning night into day have been found.

A history of the artificial lighting of streets and buildings might well be called "From Torches to Tungsten," for the earliest lights were torches, and

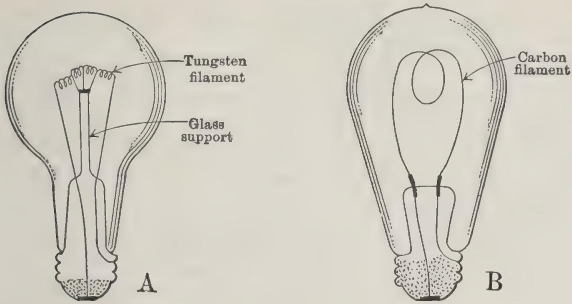


FIG. 61. INCANDESCENT ELECTRIC LAMPS
*A*, the newer tungsten lamp — *B*, the older carbon lamp

the most modern for that purpose are the tungsten electric lights we use now.

Those of us who use electricity for lighting our homes use such lamps as those shown in Figure 61. The first lamp has in it a fine wire made of the metal tungsten. The second has a filament or wire of carbon instead. These two lamps are called incandescent lamps. The word "incandescent" means white hot. When a candle gives light, part of the wax of the candle burns. When a kerosene lamp gives light, the kerosene is burning. In gas lamps, gas burns. In the case of most torches, wood burns. The electric lamps shown in the picture differ from candles and kerosene lamps and torches and gas lamps in that nothing is burning. It is not necessary to have a fire in order to have artificial light although in every lamp until the electric lamp there was a fire of some sort. In these incandescent electric lamps, the

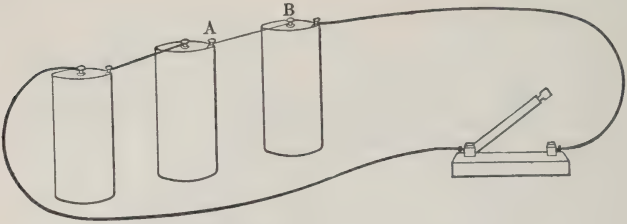


Fig. 62. An Experiment with Resistance Wire
*AB*, German silver wire

filaments become so hot that they give off light, but they do not burn. Perhaps you have been told not to leave the electric light "burning." Saying that the electric light is burning merely shows that these electric lamps are so new that many people haven't forgotten the lamps we used to use in which something actually did burn.

Figure 62 shows an experiment which can be performed easily to help you understand how it is that the wire in an electric lamp becomes hot enough to give off light. Notice that there is a piece of German silver wire in the circuit. The remainder of the wire is copper. If the switch is closed, a current of electricity will flow, and the piece of German silver wire will become hot enough to give off light. If you should feel the copper wire during this experiment, you would find that it is warm, but not hot. The reason the German silver wire becomes hot while the copper wire does not is this: The German silver wire offers more resistance than the copper wire.

When electricity flows through wire which offers a great deal of resistance, the wire becomes much hotter than when a current of the same strength flows through wire which offers just a little resistance. No material is a perfect conductor. All substances offer at least a little resistance. Therefore all wires become somewhat warmer when an electric current flows through them.

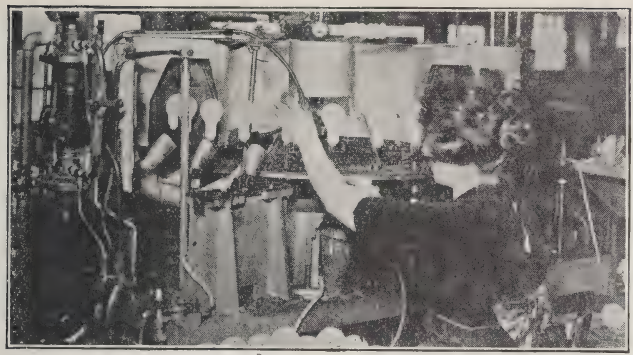
As you were told in an earlier chapter, the amount of resistance a wire offers depends not only upon the material of which the wire is made, but upon the size and length of the wire as well. If you took out the piece of German silver wire in the experiment shown in Figure 62, and put a piece of very fine copper wire in its place, the fine copper wire would become very hot, probably hot enough to melt, although copper is a good conductor. The finer the wire, the more resistance it offers, other things being equal; and the longer the wire, other things being equal, the more resistance it offers.

If you made an electromagnet like that shown in Figure 51, you probably found that the wire of the magnet became hot after you had used it for some time. When you opened the switch and broke the circuit, the magnet soon became cool. Perhaps you tried making the magnet stronger by using more than one cell in the circuit. If so, you probably found that the magnet became hot very much more quickly.

How hot a wire gets when a current of electricity flows through it depends upon the strength of the current as well as upon the resistance the wire offers.

Tungsten and carbon both offer much more resistance than copper. Do you understand now one reason why the filaments in electric lamps are made of these materials? Do you understand, too, why these filaments are small? Of course, the wires, even if they were large, could be heated white hot if a strong enough current were used, but such lamps would be very expensive to operate. Although, because it is coiled, it may not look so, the filament of the tungsten lamp is much longer than that in the carbon lamp. This is necessary because tungsten is a better conductor than carbon. The extra length of the tungsten filament makes up for the extra resistance of carbon. Of course it goes without saying that both tungsten and carbon can be heated white hot without melting.

There is an almost perfect vacuum in most of the electric lamp bulbs we use in our houses. If air were left in the carbon lamp, the carbon filament would really burn as soon as it became white hot. It would cease to give light in less than a second, because the wire would burn in two and would break the circuit. With the air pumped out, it cannot burn. If air were left in the tungsten bulb, the tungsten filament would waste away much more rapidly than it does in



*By courtesy of General Electric Company*

FIG. 63. PUMPING AIR FROM LAMP BULBS AND FILLING THEM WITH ARGON

a vacuum bulb. If you have one of the older lamp bulbs with a tip at the end, you can easily prove for yourself that there is a vacuum in the bulb. You have only to hold the end of the bulb under water and break off the tip. The water will rush up into the bulb to fill the vacuum. This experiment is much more difficult with the newer bulbs which have no tips projecting.

Some tungsten lamps, instead of having a vacuum, have the air pumped out and nitrogen or argon gas pumped in. Figure 63 shows an operator exhausting the air and filling the bulbs with argon. The tungsten filament gives a brighter light and wastes away less rapidly when this is done.

Of the two kinds of lamps shown in Figure 61, the carbon lamp is the older, and the tungsten lamp the better. Since tungsten is a rare and expensive metal,

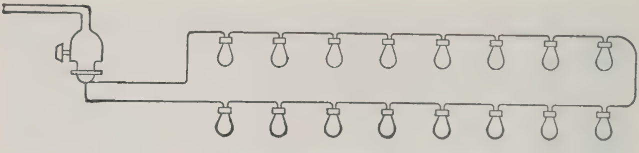


FIG. 64. LAMPS CONNECTED IN SERIES

tungsten lamps are more expensive than carbon lamps. The tungsten lamps are more easily broken, too, but tungsten lamps have two advantages: They give a whiter light than carbon lamps give; and with tungsten lamps you get more light for the same amount of money paid for electricity. A sixty-watt tungsten lamp gives more light than a sixty-watt carbon lamp. Another way of saying this is that with tungsten lamps you can get the same amount of light that you get from carbon lamps for less money paid for electricity. Because of these advantages, fewer and fewer carbon lamps are being used.

In a lamp socket, one wire is connected to the brass screw cup, and the other to the center of the socket. When the lamp bulb is screwed into the socket, the brass screw cup comes in contact with the screw at the base of the bulb, and the little piece of brass in the base of the socket touches that in the center of the base of the bulb. When the switch is closed the circuit is complete.

Figure 64 shows the diagram of a string of Christmas tree lights. When lamps are connected in series in this way, all the lights go out if the filament in one

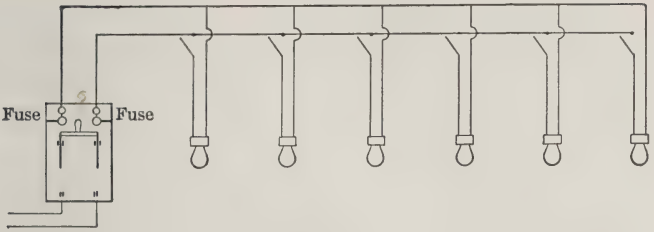


Fig. 65. Lamps Connected in Parallel

lamp breaks. If the circuit is broken, you see, the current does not flow. If the lamps in our houses were connected in series, as the Christmas tree lights are connected, all the lights in the circuit would go out when one lamp was broken. This would, of course, be very inconvenient. Moreover, if our lamps were connected in this way, we should have to have all the lights on or none. There is no way of turning one lamp off or on without turning off or on all the lamps in the circuit. This would be very inconvenient, too. Consequently a better scheme of connecting lamps in houses has been worked out. Figure 65 shows what it is. This way of connecting electrical devices is called parallel wiring. If you trace the path of the current through each lamp, you will see that each lamp can be turned off or on without disturbing the other lamps.

If there are many lights in a building, there are usually several such circuits as that shown in Figure 65.

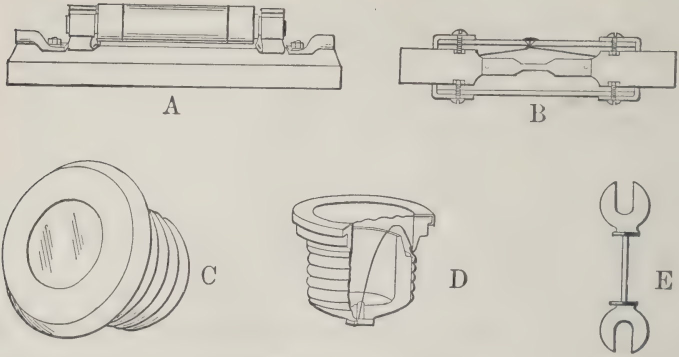


Fig. 66. Fuses

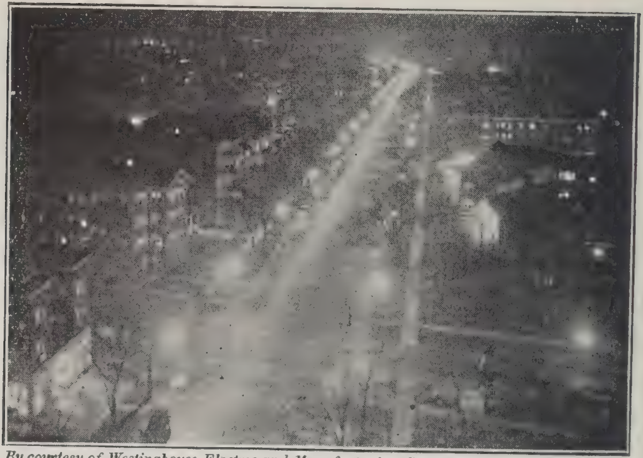
*A*, cartridge fuse — *B*, section through cartridge fuse — *C*, plug fuse — *D*, section through plug fuse — *E*, link fuse

Sometimes, even with parallel wiring, all the lights in the circuit go off at once. This happens when a fuse blows out. Notice the fuses in Figure 65. Usually not all the lights in a building go out when a fuse blows out because, as you have been told, not all the lamps are on one circuit. Each branch circuit has separate fuses. Of course, if one of the fuses at the entrance switch blew out, all the lights on the branch circuits would go out.

There are many kinds of fuses, as you can see from Figure 66. The ones used in the branch circuits in our houses are, as a rule, like the one shown in Figure 66 C. Those used on the main circuit at the entrance switch may or may not be of the same type. You should be able to understand now why a fuse "blows out." It contains a strip or wire of metal which has a low melting point. This piece of metal offers a certain amount of resistance. When a stronger current than the current the fuse is intended to carry goes through it, the resistance the metal offers makes it become so hot that it melts and breaks the circuit. Fuses are marked to show how strong a current they can carry without melting. Suppose the fuses in the branch circuit shown in Figure 65 are six ampere fuses. Suppose, too, that the lamps are 60 watt lamps. Since a current of one-half ampere is used by each lamp, if all the lamps shown in the diagram are turned on, a current of three amperes flows through the fuses. This current the fuses carry safely. However, if a heater using six amperes were used in place of one of the lamps, the current flowing through the fuses when the five lamps were on would be eight and one half amperes, which is more than the fuses could carry. The fuse metal would melt and break the circuit. As you have been told, fuses blow, too, when a short circuit causes a stronger current than the fuses can carry to pass through them. The fuses act as safety valves in the circuit.

In case a lamp doesn't light when you close the switch, one of several things may be the difficulty:

The power may be off.
The filament in the lamp bulb may have broken.
A fuse may have blown.
The lamp may not be screwed into the socket far enough to make connections.



*By courtesy of Westinghouse Electric and Manufacturing Company*

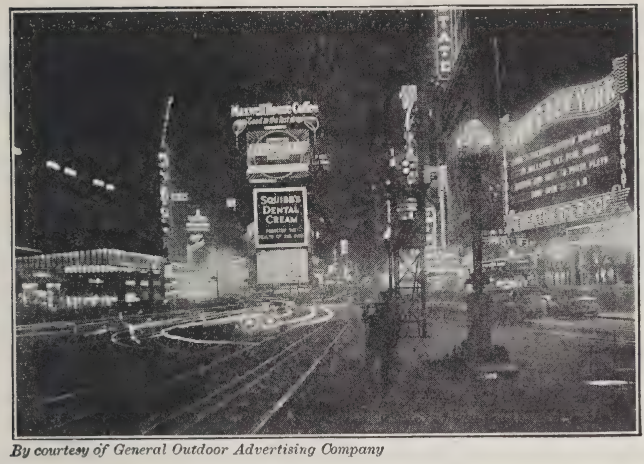
FIG. 67. A WELL-LIGHTED RESIDENCE STREET

If there are two switches in the circuit, one of them may still be open.

If an extension cord is used, one of the wires in it may be broken.

There may be poor connections somewhere in the circuit.

Small incandescent lamps are used in flashlights, automobile headlights, and for Christmas-tree lamps. Large incandescent lamps are used to light buildings and streets and in electric signs. Figure 67 shows a well-lighted residence street. Did you ever stop to think how much safer good lighting makes such a street? The lamps shown in the picture are built with refractors so that most of the light is thrown along the street. Much of the light given by lamps without refractors goes up toward the stars and is



*By courtesy of General Outdoor Advertising Company*

FIG. 68. TIMES SQUARE, NEW YORK

wasted so far as lighting the street is concerned. Figure 68 gives some idea of the extent to which incandescent lamps are now used in advertising. Think of the immense number of lamps used in the part of the city shown in the picture. A single large electric sign at Atlantic City contains twenty-five thousand tungsten lamps.

Incandescent lamps such as those shown in Figure 61 were not the first electric lamps. The first electric lamps were arc lamps. Figure 69 shows an electric arc. Figure 70 shows an enclosed arc lamp. In each case there are two rods of carbon. When two carbon rods are made to touch each other while a strong current is flowing through, the ends of the rods become very hot. When the rods are moved a

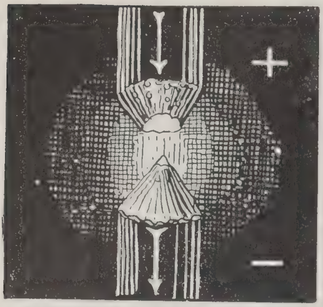


Fig. 69. An Electric Arc

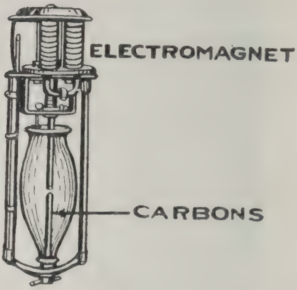


Fig. 70. An Enclosed Arc Lamp

quarter of an inch or so apart, the current keeps on flowing across the gap between the rods because there is now a path of carbon vapor between the ends of the two rods. This carbon vapor offers so much resistance that it becomes white hot and gives off a very bright light. In the enclosed arc lamp, an electromagnet is used to keep the carbon rods in their proper positions.

It may surprise you to know that arc lamps were invented some sixty years before they were used for anything except experiments. Sir Humphry Davy invented the arc lamp. He used two thousand cells to furnish the needed current. Since so high a voltage was needed, the arc lamp remained practically useless until after generators had been invented and built.

Arc lamps are very efficient lamps; they give off a great deal of light for the power that they use. Because of the very bright light that they give, they are, in many cases, used in stereopticons and in moving picture machines. They are too large and too bright to be used in small rooms in houses. A few years ago, most of the electric street lamps were arc lamps. Now the arc lamps have, for the most part, given way to tungsten lamps.

Some of the electric lamps now being used in electric signs are neither lamps with filaments, nor arc lamps, but are the so-called "rainbow tubes." These tubes are glass tubes which glow with a colored light. The tubes may be bent to form words or to make designs. Electricity at high voltage leaps from one end to the other of these tubes. To make it possible for an electric spark to jump so far, there must be an almost perfect vacuum in each tube. If there were a perfect vacuum, however, the tubes would not be rainbow tubes. The color is due to the presence of a small amount of some kind of gas. If the gas is neon, the tubes glow with a red light. With other gases which belong to the neon group, green, blue, and other colors may be produced. Neon tubes are being used, not only in advertising, but also on aviation landing fields, because their peculiar red light goes through fog better than any other artificial light. Neon tubes are playing an important part in experiments with television, too. In fact, although they are new, rainbow tubes already have proved to be so useful that their manufacturers claim that they represent the biggest step forward since the invention of the incandescent lamp in using electricity to produce light.

## XX. THE STORY OF THE INVENTION OF THE INCANDESCENT ELECTRIC LAMP

A guide in a large factory where electrical apparatus is made once told a visitor, just for fun, that the inventor of the incandescent lamp got the idea of the lamp by seeing lightning jump from one prong to another of a fork in a pickle bottle. The visitor, the guide learned later, was Thomas A. Edison. Imagine how embarrassed the guide must have been when he found that he had told that ridiculous story of the lightning in the pickle bottle to Edison, the inventor of the incandescent electric lamp.

Soon after the electric battery came into common use, it was found that, when a current of electricity flows through wire which offers great resistance, the wire quickly becomes hot. Of course this heating of a wire by means of electricity immediately appealed to scientists as a means of producing artificial light. When they tried making an incandescent lamp, they found that there were many difficulties. In fact there were so many difficulties that in 1879, less than fifty years ago, a group of leading scientists decided that the problem of developing a system of lighting with incandescent electric lamps was too hard a problem for any one to solve. Incandescent lamps had been made, but they were so crude that they were not considered important. Within a few months after these scientists had discussed the matter, Edison had practically solved the problem which they thought could not be solved.

In 1878 Edison had a chance to examine an electric lighting system which was being carried around the country with a traveling circus. At this time Edison had just finished some important work which he had been doing, and he decided that he would start work upon the problem of an electric lighting system. A number of his friends soon became interested in this problem and encouraged him to go on with his work upon it. The arc lights Edison had seen were much too big and gave much too bright a light to be used in a room in a building. In buildings small lights were needed, the electricity for which could be distributed to the buildings just as gas was. In thinking over the problem Edison saw that there were two possibilities: small arc lamps and incandescent lamps. For several reasons he gave up the idea of small arc lamps and started on the problem of incandescent lamps.

Edison thought at first of using fine platinum wire in his lamps. Platinum wire has high resistance, is easily heated to white heat, and had been used in many experiments of this sort. After careful experiments Edison found that platinum wire wastes away when it is kept at white heat. He decided that this was due to the action of the air on the wire when it was white hot. To avoid this wasting away, he put the platinum filament in a glass bulb and took out as much of the air as possible from the bulb. He improved the air pumps then in use so that he could exhaust from the bulb all but one millionth of the air in it.

After he had produced the vacuum bulb, however, another difficulty arose. A current of a certain strength was needed to make the platinum wire white hot. When, however, the current became slightly stronger, the filament became so hot that it melted. The task of regulating the current so that the platinum filament would not melt was a difficult one. Edison invented many devices for preventing the filament from melting, and patented some of them, but none of them proved to be practicable. He substituted other metals for platinum, but they did not work any better. Finally, after thirteen months of experimenting, Edison decided that he had made no real progress in solving the problem of an electric lighting system.

As he was sitting in his laboratory one day, he picked up, without thinking, a little lump of a mixture of tar and lampblack. Lampblack is carbon.

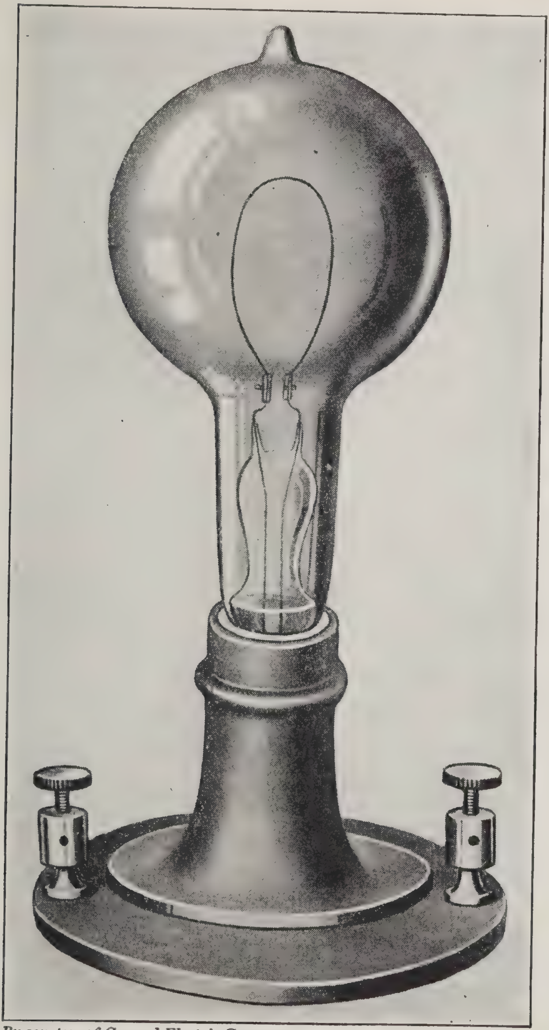
He had been using this mixture in work with the telephone transmitter. Half an hour later, after he had been thinking of the substances of which the filament for an electric light bulb might be made, he noticed that he had rolled the tar and lampblack into a fine thread. Anything which looked like a wire appealed to him as being a possibility as a filament for a lamp. Why not use this? Carbon, of course, burns in the air, but it can't burn in a vacuum, and he had already made a globe with an almost perfect vacuum. He knew that carbon would not melt as the platinum had done.

He set his assistants to work at making fine threads of carbon and tar. Finally one was placed in a bulb, the air was pumped out, and a current was sent through the filament. A good light was produced, but the filament soon burned out. Edison decided that this was due to tiny particles of air caught between the particles of powdered carbon. This air could not be removed with the air pump. In addition, the filament became so brittle that a little jar would break it. The idea of using a carbon filament was evidently a good one, but the carbon filament would have to be a better one than the one he had made.

It occurred to Edison that an ordinary piece of cotton thread could be made into a carbon thread by charring it. Cotton contains carbon. Heating the thread would drive away the other materials and leave the carbon. In such a filament there would be no air which could cause the filament to burn. He sent an assistant for a spool of thread. A short length of the thread was bent into a hairpin shape and was put into a mould. This mould was then put into a furnace. It was allowed to stay there for five hours. The mould was then opened, and the carbonized thread was taken out. It broke. Another piece of thread was put in the mould and carbonized. It also broke.

All night Edison and his assistant worked at making a filament. All the next day they worked, and the next night again, without stopping to rest. At the end of that time they had succeeded in producing one filament out of a whole spool of thread. Having made it, they had next to take it to the glass blower's house to have it put into a lamp. The assistant carried the tiny bit of charred thread to the glass blower's bench as if it were a great treasure. Edison followed close at the heels of his assistant. Just as they reached the bench the filament broke.

They turned back to the laboratory once more. Late that afternoon they had another perfect filament. This time a jeweler's screw driver fell against it and broke it. They went to work once more. Before night a filament was made and successfully inserted in a bulb. The air was pumped out of the



*By courtesy of General Electric Company*

FIG. 71. REPLICA OF EDISON'S FIRST INCANDESCENT LAMP

bulb, and the bulb was sealed so that no more air could come in. The current was then turned on, and Edison and his assistant were tremendously pleased to see that the lamp worked well. Figure 71 shows a replica of this first incandescent lamp.

The current they turned on in the beginning was not strong, but they gradually increased it. Finally the carbon filament was heated to a heat which would have melted a platinum filament instantly. This little lamp burned for forty-five hours. Then the carbonized thread broke. The two men were happy, however, because they were sure that they were near the solution of the problem of making a satisfactory incandescent electric lamp.

In order to be a commercial success Edison figured that the lamp would have to give light for at least two hundred hours. To find a filament which would do this, Edison began carbonizing all sorts of materials. The entire working force of the laboratory was set to work carbonizing straw, paper, cardboard, wood splinters, and a hundred other things. One of Edison's friends tells us that in those days nothing was safe and that doubtless, if a lame man had come into the laboratory with a crutch, it, too, would have been made into carbon filaments. Good results were obtained with cardboard filaments, but Edison was not satisfied. At length he made a filament from the border of a bamboo fan. This filament was better than anything he had yet tried. He decided that bamboo was the best material from which to make these filaments. He thought that somewhere in the world there was probably a kind of bamboo which would make a perfect filament.

Then began a search for bamboo which took men to the far corners of the earth and which cost nearly one hundred thousand dollars. Edison learned that there were more than a thousand varieties of bamboo, and he wanted a sample of each variety. To get specimens, one of his workers traveled thirty thousand miles through the Malay Peninsula, Burmah, and southern China, and had many exciting encounters with wild beasts in the jungles. Another man went to Japan to get specimens of bamboo from there. One worker went up the Amazon to get specimens from the tropical forests of South America. Others went to Mexico, British Guiana, and Ceylon. So interested were Edison's employees in the search that, when Edison read to some of them a cablegram saying that one of his men who had been sent to Havana had died of yellow fever, twelve men volunteered to take that man's place.

Bales of bamboo reached Edison's laboratory. All the samples were tested. Three varieties of bamboo from the Amazon Valley, and one kind of cane from there, gave excellent results, but were very difficult to obtain. Finally a contract was made with a

Japanese man for bamboo. The Japanese bamboo plants were cultivated and cross-fertilized, and satisfactory filaments were made from this bamboo. Carbonized bamboo filaments were used in all incandescent lamps until, a number of years later, "squirted" carbon filaments were found to give better results.

Soon after he had made his first satisfactory lamp Edison made a number of lamps, which were strung along a wire and were hung from trees in Menlo Park where his laboratory was at that time. The lamps were allowed to burn day and night for a week. Thousands of people came to see the wonderful new lights. They were considered a great success.

Of course Edison's problem was not entirely solved when he had succeeded in inventing the lamp bulb. There was the problem of inventing machines to make bulbs in large quantities. There was the big problem, too, of planning and building power plants which would furnish electric current to every building which was wired for electric lamps. So successfully were these problems solved that electricity, as you know, is now considered the best means in the world of producing artificial light.

## XXI. TRADING ELECTRICITY FOR HEAT

Thirteen of the electric devices listed on page 2 are devices by means of which we can use an electric current to produce heat. If you were to make a list of all the ways in which you use artificial heat in your homes, the list would probably read somewhat like this: cooking; heating the air in the rooms to the right temperature; heating water for bathing, laundry, house-cleaning, and dishwashing; ironing; relieving pain; drying and curling hair. So many devices for using electricity to produce heat have been invented that it is now possible for us to do all of the things in the list without having a fire in our houses. Instead of a coal or a gas or an oil range for cooking we may have an electric range. With such a range there is no smoke, no ash, and no danger of escaping gas. Whole houses may now be heated with electric heating systems. Electric water heaters may be had. Unfortunately, however, using electricity to heat our houses, to cook large amounts of food, and to heat large quantities of water is much more expensive than using coal or oil or gas to do these things. As a result there are not nearly so many electric ranges and electric heating systems and electric water heaters as there are smaller heating devices such as those shown in Figure 72.

The electric iron was the first electric heating device invented. Electric irons are still the commonest of all electric heating devices. If a home contains only one device for trading electricity for heat, that one device is likely to be an electric iron. Electric toasters are almost as common.

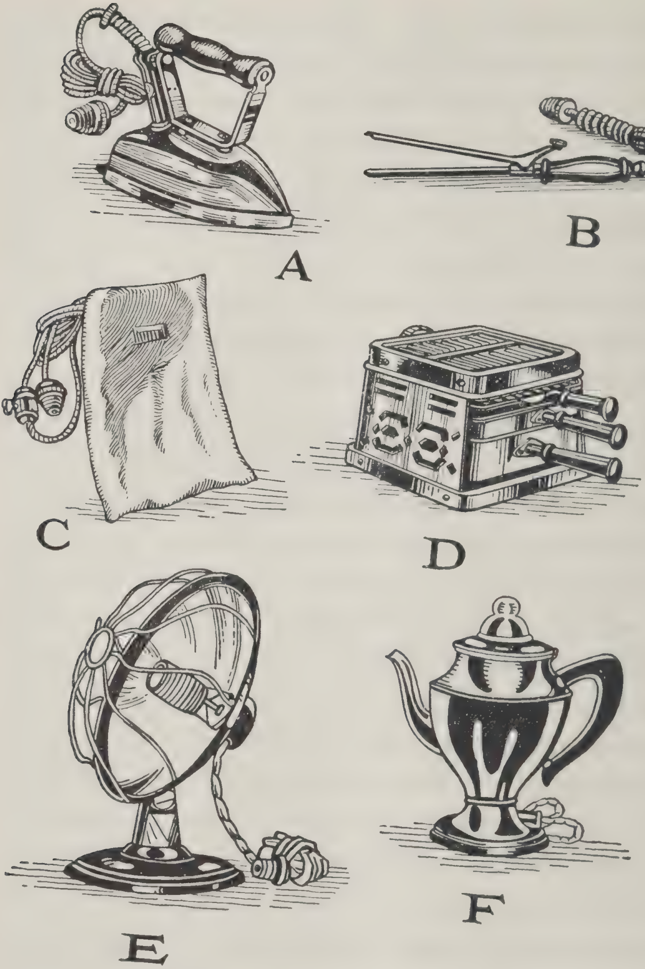


FIG. 72. ELECTRIC HEATING DEVICES
*A*, laundry iron — *B*, curling iron — *C*, warming pad — *D*, grill — *E*, heater — *F*, percolator

If you could take apart and examine all the heating devices shown in Figure 72, you would find them all alike in this way: Each one contains resistance wires or strips which become hot when an electric current flows through them. In most electric toasters these resistance wires or strips can be seen. In most electric plates and grills and heaters they can be seen, too. In many heating devices the heating elements are hidden. Figure 73 shows the heating unit taken from an electric iron. The resistance wires are wound on a sheet of mica. In incandescent electric lamps the resistance wires become white hot; in most electric heating devices they are not heated to so high a temperature.

The resistance wires of the early electric heating devices were made of iron or of German silver. Devices made with iron or German silver wire were satisfactory while they lasted, but they soon wore out. Various alloys, or mixtures of metals, have been found to be better for the purpose than iron or German silver. In many electric toasters, for example, an alloy of nickle and chromium is used.

It is not only in our homes that electricity is used to produce heat. Of course many of the kinds of electric heating devices we use in our homes are also used in hotels, restaurants, shops, and factories. In addition, there are other heating devices which, as a rule, we do not use in our homes. Electric soldering

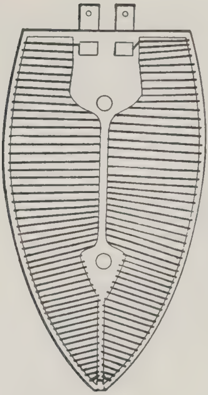


FIG. 73. HEATING UNIT OF AN ELECTRIC IRON

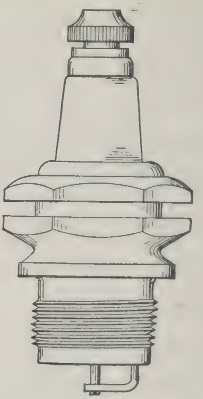


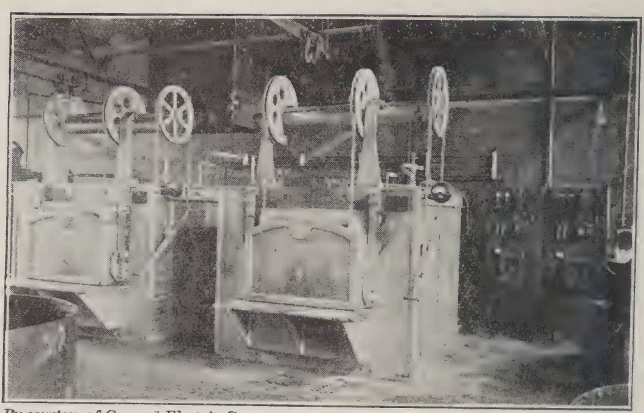
FIG. 74. A SPARK PLUG

irons, for example, are common. In the gasoline automobiles of the world, millions of spark plugs are used to heat the gas in the cylinders of the engines so that it will explode and drive the cars. The electric furnace is still another important electric heating device.

Figure 74 shows an automobile spark plug. When the circuit is complete, an electric spark jumps from the tip of one of the wires of the spark plug to the tip of the other. This spark heats the gas in the cylinder and causes the explosion.

There are many types of electric furnaces. In all of them, as you should expect, the current flows through some substance which offers great resistance. In an electric arc furnace, an arc somewhat like that shown in Figure 69 is formed when the current is turned on. The walls of the furnace are built of materials which serve to shut the heat in. Such a furnace produces the highest temperature we have yet found out how to produce. In such a furnace the metals with the highest melting temperatures melt as if they were wax. A temperature of 3500 degrees Fahrenheit is needed to melt platinum, one of the difficult metals to melt. The temperature of some electric furnaces can be raised to 7000 degrees Fahrenheit. This is very much hotter than the highest temperature which can be produced by burning gas or coal or wood or any other such fuel. Even diamonds, one of the hardest of all substances, can be melted in an electric arc furnace.

Not only can diamonds be destroyed in the terrific heat of an electric furnace, but they can be made, too. Scientists have long known that the diamond is merely one form of carbon. A diamond is really the same material as the lead in your pencil and the soot in your chimney. But manufacturing a colorless carbon crystal out of ordinary black carbon is possible only in the heat of an electric furnace. Even in such a furnace only very small diamonds have been made. Diamond merchants need not worry for fear diamonds will become cheap because they can now be manufactured. A large diamond that has been mined from the earth can be bought for what it costs to make a tiny, tiny diamond in an electric furnace.



*By courtesy of General Electric Company*

FIG. 75. ELECTRIC FURNACES

Rubies and sapphires can be manufactured in an electric furnace, too. Even jewel experts find it hard to tell the rubies and sapphires made in electric furnaces from the "real" ones which are found in rocks. In Switzerland and in some parts of France, electric current is cheap because there is much water power which is used for generating electricity. In these two countries millions of carats of rubies and sapphires have been made in the past few years.

In the heat of the electric furnace quartz can be fused and can then be made into flasks for use in science laboratories and into "pyrex" kitchen ware.

Figure 75 shows two electric furnaces which are used in annealing and heat-treating steel. The operating temperature of these furnaces is about 1650° Fahrenheit. Many of the alloys, or mixtures of metals, are made in electric furnaces.

Carborundum, a substance much used in grinding-wheels and whetstones because it is very, very hard, is another of the products of the electric furnace. Carborundum was first made by accident by a scientist who was trying to make artificial diamonds. Much of the carborundum used in this country is made at Niagara Falls where electric current is cheap.

Another of the remarkable kinds of work done in these electric furnaces is the changing of the nitrogen in the air into a form in which plants can use it. One of the materials which all plants must have is nitrogen. There is much nitrogen in the air — nearly four fifths of the air is made up of it; but, strange as it may seem, very few plants can use this nitrogen from the air. Most plants have to get their nitrogen from the soil where it is combined with other things. As plants grow in the same soil year after year, the supply of nitrogen becomes gradually less unless nitrogen is added to the soil in some way. There are several ways in which nitrogen can be returned to the soil. One of the easy ways is to buy nitrates and add them to the soil. Nitrates are compounds which contain nitrogen. Until recently the only way of getting these nitrates was to get them from the parts of the world where they are plentiful. The great deposits of nitrates which can be used as fertilizers are in South America. Now other countries do not have to depend altogether upon South America for nitrates because it has been found that, by using electric arc furnaces, nitrates can be manufactured. In the electric furnace the nitrogen of the air is made to unite with oxygen. This compound of nitrogen and oxygen is then made into nitrates for fertilizer. In the mountainous regions of Europe where electric current is cheap, there are now many factories for the "fixation" of the nitrogen of the air.

The compound of nitrogen and oxygen is by no means the only compound made in electric furnaces. Chemists have produced many new compounds in these furnaces. They have used them, too, in breaking up compounds already known. Perhaps the terrific heat of these furnaces will help scientists find out still other secrets and solve problems that are now unsolved.

# USING ELECTRICITY TO DO WORK

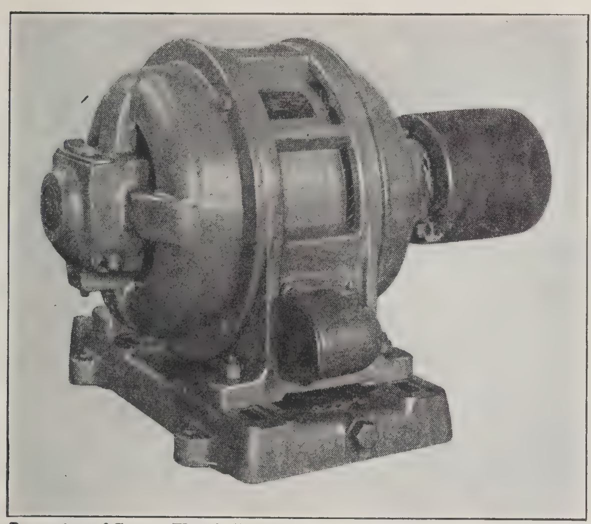
## XXII. THE ELECTRIC MOTOR

If you were asked to make a list of the things which the name "Holland" or "The Netherlands" suggests to you, surely one of the things you would list would be windmills. Most tourists have enjoyed their trips to the Netherlands partly because of the quaintness of the Dutch windmills. Now the Dutch windmills are disappearing one by one; and electricity is to blame. The Dutch miller has found that, if he uses an electric motor, he can make electricity do the work which the wind used to do for him. Motors are gradually taking the place of the windmills.

An electric motor is certainly not so quaint and picturesque as a windmill, but it has certain advantages. It is easier to keep an electric motor in order than it is to keep a big windmill in order. Many Dutch millers have found it cheaper to buy electricity for running an electric motor than to use free wind power and pay the repair bills on the windmill. One reason that wind is used for power to a greater extent in the Netherlands than in other countries is that, in the Netherlands, wind is more dependable as a source of power than in most other places. There are many windmills on the farms in our country.

On many days these windmills are idle because there is not enough wind to make them turn. Although on most days there is enough wind to turn the Dutch windmills, electricity is an even more dependable source of power. The Dutch miller has only to close a switch and the motor begins to do its work. He can make the motor work very rapidly or very slowly as he chooses. He can shut off the power and stop the machinery at any moment he chooses. The motor can be used not only to grind grain but to pump water also, just as the windmill can. When electric motors are so easy to keep in repair and so easy to operate, do you blame the Dutch millers for giving up their windmills for motors?

Figure 76 shows an electric motor. Perhaps you are thinking as you look at the picture, "This looks very much like a generator." It does. Motors *are* very much like generators. All generators can be used as motors, and all motors can be used as generators. If you wished to use the motor shown in Figure 76 as a generator, you would connect the armature to a steam engine or to some other such machine. This machine would turn the armature of the motor-generator. If wires were connected properly, a current of electricity would flow through the circuit. In short, you move the armature, and a current of electricity is generated. If you wish to use the machine as a motor, you send a current of



*By courtesy of General Electric Company*

FIG. 76. AN ELECTRIC MOTOR

electricity through the coils of the motor, and the armature turns. The story can be told very simply in this way:

Generator: motion → electric current
Motor: electric current → motion

Figure 77 A shows the diagram of a very simple motor. Toy motors similar to this one can be made fairly easily. It is a combination of an electromagnet and permanent magnets. The armature is an electromagnet fastened on a pivot so that it is free to turn. The commutator is made of two pieces of brass insulated from each other. One end of the coil of wire of the electromagnet is fastened to one

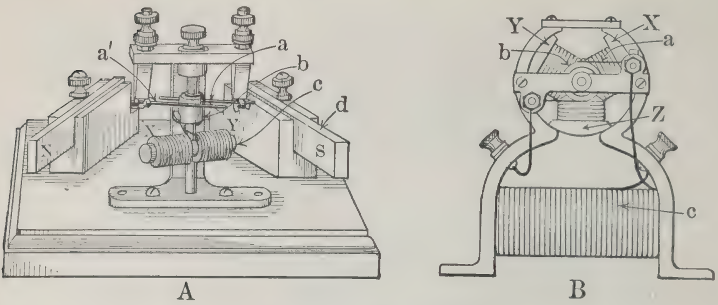


Fig. 77. Two Simple Motors

*A*,
*a*, *a′*, brushes —
*b*, commutator —
*c*, electromagnet armature —
*d*, permanent magnet
*X*, *Y*, poles of armature

B,
*a*, brush —
*b*, commutator —
*c*, field magnet —
*X*, *Y*, *Z*, poles of armature

half of the commutator, the other end to the other half. The commutator is fastened to the armature so that it turns when the armature turns. The brushes carry the current to and from the commutator. When the switch is closed, the current flows through the armature. Let us suppose that the current flows through the magnet in such a direction that *X* becomes the north pole of the magnet and *Y* the south pole. You remember that opposite poles attract each other, and that similar poles repel each other. The north pole of the permanent magnet repels the north pole of the electromagnet, and attracts the south pole. The south pole of the permanent magnet repels the south pole of the electromagnet, and attracts the north pole.

The armature, therefore, turns halfway round. By the time the armature has turned halfway round, brush *a* touches the half of the commutator which brush *a′* touched at the beginning. The current now flows through the electromagnet armature in the opposite direction. The poles of the armature are changed because, as you were told in an earlier chapter, changing the direction of the current changes the poles of an electromagnet. *Y* becomes the north pole, and *X* the south. Again opposite poles attract and similar poles repel, and the armature turns halfway round again. Again the poles are changed, and again the armature makes a half-turn. Since the poles of the armature magnet are changed every half-turn, the armature continues to rotate.

Most toy motors are similar to the one shown in Figure 77 B. The armature of this motor has three "poles." Of course magnets have only north poles and south poles. The current flows through only two thirds of this armature at a time. The end of one of the parts through which the current is flowing is the north pole, and that of the other is the south pole. The third part of the armature is not magnetized. This third part is spoken of as the "neutral pole." Let us suppose that, when the current is first sent through the motor, *X* is the north pole, *Y* the neutral pole, and *Z* the south pole. As the armature rotates the poles change in this way:

| | | | | | | |
|---|---|---|---|---|---|---|
| *X* | *N* | *N* | *Neu* | *S* | *S* | *Neu* |
| *Y* | *Neu* | *S* | *S* | *Neu* | *N* | *N* |
| *Z* | *S* | *Neu* | *N* | *N* | *Neu* | *S* |

Notice that in this motor the field magnet is an electromagnet, not a permanent magnet. The poles of the field magnet do not change as the armature turns. The poles of the field magnet attract and repel the poles of the armature in such a way that the armature rotates.

Most motors are considerably more complex than the two simple motors about which you have been told. Some are made to be used with a direct current only, some are made to be used only with an alternating current, and some can be used with either an alternating or a direct current. As a rule, the field magnets are electromagnets. All the kinds of motors are alike in that it is the action of the magnetic field of the field magnet upon the magnetic field of the armature which causes the armature to rotate.

In many cases the speed of an electric motor is regulated by means of a rheostat, about which you were told in an earlier chapter.

Whenever you see electricity being used to move anything, you can be almost sure that an electric motor is being used. It is true that the electro-

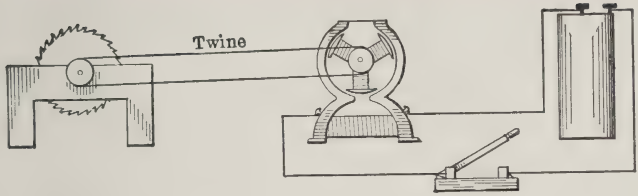


Fig. 78. Using a Toy Motor to Run a Toy Saw

magnet of a telegraph sounder pulls the armature down, and that the magnet in a bell pulls the clapper over, and that a big lifting magnet may make the iron and steel jump up to it for a little way, but a simple magnet can move things for only a short distance, and it cannot make anything turn round and round. Only a motor can do that.

Whenever you wish to turn a machine by means of a motor, you must connect the armature of the motor with the machine you wish to turn. This can be done by means of a belt or a rod or some other such device. Figure 78 shows a toy motor being used to run a toy saw.

More and more of the work of the world is being done by electric motors. The Dutch windmill is by no means the only servant which is being replaced by electric motors. In our homes, the work the electric motor does is chiefly work which used to be done by hand. Electric washing machines, electric sewing machines, vacuum cleaners, electric polishers, and electric food-grinders are great labor saving devices. Each one of these devices is run by an electric motor.

Dentists used to drill for fillings in teeth by means of drills which they turned with foot-treadles. Now they use electric motors to turn the drills.

The first phonographs were run by spring motors. The spring motor had to be wound up by hand. Now it is possible to have a phonograph run by an electric motor instead of a spring motor.

Some kinds of work done now by electric motors were formerly done by horses or mules. In coal mines, for example, the coal used to be hauled to the lifting cages in cars pulled by mules. In many mines it is now carried in cars pulled by little motor-driven engines. We now have electric automobiles instead of horse-drawn carriages. Of course most of our automobiles are gas cars, not electrics. Even in gas cars, however, electric motors play an important part. An electric motor is used to start the gas motor. There is no question but that many, many people who now drive gas cars would not do so if they had to crank the cars in order to start them.

The first street cars were drawn by horses or mules. Now they are driven by electric motors. Figure 79 shows something of how this is done. The current flows from the generator through the trolley wire. It comes down through the trolley

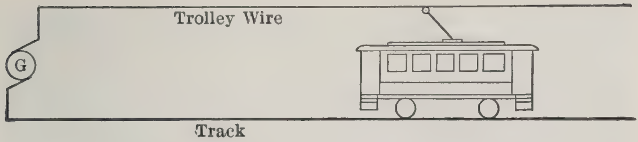


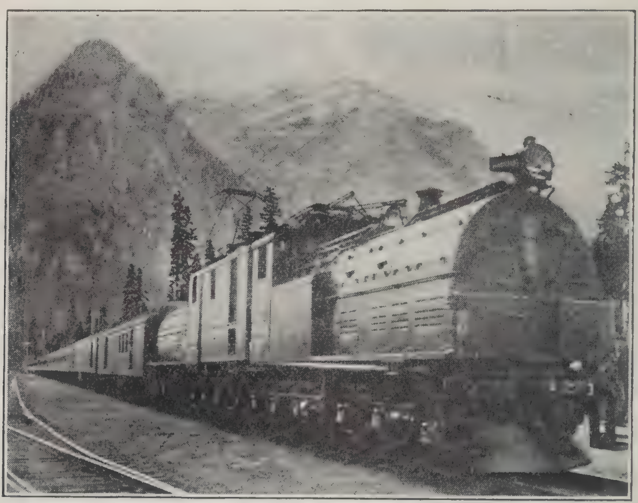
FIG. 79. DIAGRAM OF A STREET CAR CIRCUIT

pole and the control box to the motor. It goes from the motor through the wheel of the car to the track, and back to the generator through the metal rails and the ground. The motor, as it turns, turns the wheels of the car. The motorman shuts off the current, or makes it weaker or stronger as he pleases.

In some cases the electric motor does work which used to be done by water power. Most great flour mills, for example, formerly were built near waterfalls. The machines were driven by water wheels turned by the swiftly moving water. Many flour mills are now built far away from waterfalls. In most of these mills electric motors are used to do the work. Even though the mills are far away from waterfalls, the waterfalls may still be doing the work indirectly, for the electricity for the motors may be generated in hydroelectric plants. Electric motors make it possible to use the power of rushing water far away from the water itself.

The elevators in most high buildings were hydraulic elevators; now most elevators are run by electric motors.

The hammers and riveting machines used in

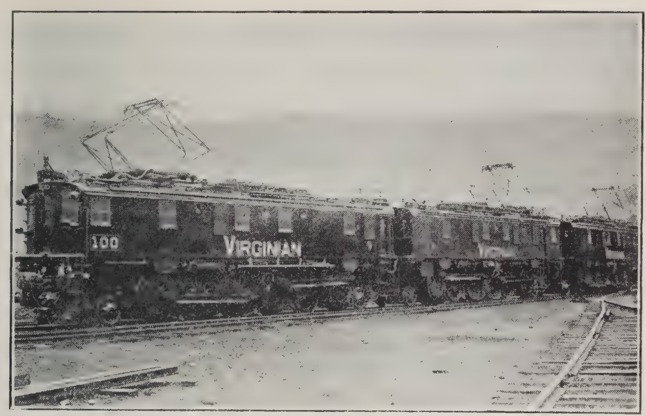


*By courtesy of Chicago, Milwaukee and St. Paul Railway*

FIG. 80. AN ELECTRIC LOCOMOTIVE

building skyscrapers may now be driven by electric motors instead of being driven by compressed air.

Some kinds of work now done by electric motors were formerly done by steam engines. Figure 80 shows a huge electric locomotive. The Chicago, Milwaukee and St. Paul Railway uses this locomotive to pull one of its fast passenger trains through the mountains. Locomotives of this sort are being used instead of steam locomotives by many railroads. Figure 81 shows the largest electric locomotive in the world. Boats are now, in many cases, driven by electric motors instead of by gas engines or steam engines. In factories, ever so many machines which were formerly run by steam engines are now run by



*By courtesy of Westinghouse Electric and Manufacturing Company*

FIG. 81. THE LARGEST ELECTRIC LOCOMOTIVE IN THE WORLD

electric motors. Does the fact that the motor is replacing the steam engine mean that the steam engine is less important than it used to be? A man who heard a lecture about the rate at which we are using up our supply of coal said, "Why worry? When the coal runs out we can use electric motors altogether instead of steam engines to do our work for us." What he forgot was this: The electric current for an electric motor must be generated in some way, and in very many cases it is generated by a generator driven by a *steam engine.* The electric locomotive shown in Figure 81 is driven by an electric motor instead of a steam engine. The electricity for such a locomotive might come from a power plant where the generators are driven by steam engines. If it does, substituting an electric motor for a steam engine on the locomotive really means, not that the steam engine has been done away with, but merely that the steam engine has been moved from the locomotive to the power plant. Of course, in some cases the generators at the power plants are driven by water power. The power which drives the locomotive shown in Figure 80 comes in part from the hydroelectric plant shown in Figure 19. For short and easy hauls some railroads are now using locomotives which carry their power plants along with them; gasoline engines drive generators which furnish current for the motors. Only in case the current for the motor comes from a plant where the generators are not driven by steam engines is the electric motor a real rival of the steam engine.

It is really wasteful to use electric motors instead of steam engines if we have to use steam engines to run the generators to furnish electricity for the electric motors. Less energy is wasted if the steam engines in a big boat are connected to the propeller than if the propeller is connected to an electric motor and the steam engine is used to run the generator to furnish current for the motor. However, the gain in convenience is enough to make up for the loss in energy. An electric motor is very easy to operate. It takes some time for a steam engine to get under way. It takes some time for it to slow down and come to a stop. The electric motor can be started and stopped in a much shorter time. The speed of the electric motor can be controlled very easily, too.

In some cases the electric motor doesn't replace any other way of working. In those cases it does work which wasn't done before the motor was invented. For example, there were electric motors before there were moving picture machines, and motors have been used to wind and unwind the films from the beginning. There were no "iceless iceboxes" in our homes until after the electric motor had come into common use. The principle upon which such a system works is that evaporation has a cooling effect. A certain kind of gas is turned into a liquid by means of a compression pump. This liquid is then allowed to evaporate in pipes. As it does so it absorbs heat from the pipes and from any objects near the pipes. After the liquid has evaporated, the gas is once more changed to a liquid by the compression pump. The liquid again evaporates. This evaporating and condensing is repeated over and over again. The part the electric motor plays is, of course, to drive the compression pump. In large artificial-ice plants, many of the pumps are driven by steam engines instead of by electric motors.

The electric motor ranks as a very important invention. You should be able to see now some of the reasons for this. What other kind of machine can be used to do such simple things as mixing a drink at a soda fountain and polishing a pair of shoes, as well as to do such work as drawing a string of heavy freight cars or driving an ocean liner across the sea?

# ELECTROPLATING

## XXIII. PLATING WITH METALS BY MEANS OF ELECTRICITY

The alchemists of old worked in their laboratories day after day after day in their attempts to change cheaper metals into gold. They tried to find the "philosopher's stone" which would enable them to do this. All their efforts were in vain. No one has ever found the "philosopher's stone," but scientists have found a way of making other metals look as if they had been turned into gold. They have learned how to use electricity to put a thin coating of gold on objects made of other metals, and so make the objects look as if they had been changed to gold. A ring, for example, which is made of brass and has had a thin layer of gold put on the outside looks as if it were pure gold. Using electricity to put a thin coating of a metal on an object is called electroplating. Gold plating is not the only kind of electroplating.

If you could examine, inside and out, all the metal things you use, you would find that many of them are not made entirely of the materials of which they seem to be made. Perhaps some of your silver is not pure silver as it looks to be, but is brass with a silver coating. The water faucets in your homes are probably not pure nickel, but are nickel-plated brass. Your notebook rings are nickel-plated steel. The handles of your scissors are not nickel, but nickel-plated steel. Your alarm clock may be brass masquerading as nickel or silver. The nickel trimmings on your kitchen stove are probably merely nickel-plated.

There are two reasons for coating these things made of brass or iron or steel with silver or nickel. Nickel and silver are thought by many people to be more beautiful metals than brass and iron and steel, and nickel and silver do not rust or corrode as iron and steel and brass do. Of course you may wonder why these plated articles are not made of pure nickel or pure silver. The answer is that they would be very much more expensive if they were. Sterling silver spoons, for example, are much more expensive than silver-plated spoons. How expensive silver-plated spoons are depends partly upon how thick a layer of silver plating they have. Silver-plated spoons are very satisfactory unless they have been used so much that the silver plating has been worn away in spots and the brass is exposed.

The discovery that electroplating can be done came soon after the discovery that when an electric current flows through water to which a little salt or acid has been added, the water is broken into the hydrogen and oxygen of which it is made. Using an

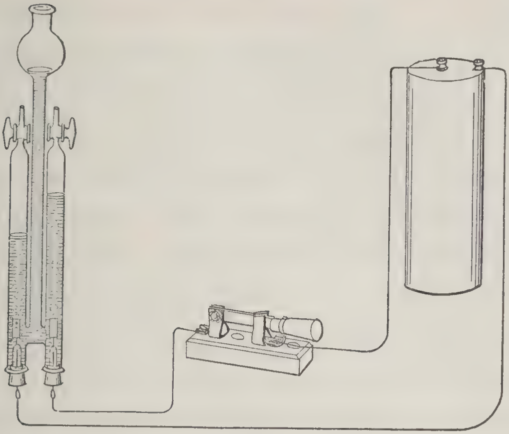


FIG. 82. DIAGRAM SHOWING THE ELECTROLYSIS OF WATER

electric current to break up water into hydrogen and oxygen is called the electrolysis of water. Figure 82 shows the apparatus for the electrolysis of water. The bubbles rising from the wire connected to the zinc or negative pole of the battery are bubbles of hydrogen; the bubbles rising from the other wire are bubbles of oxygen. If it is possible to use an electric current to get hydrogen and oxygen from water, scientists argued, it should be possible, if an electric current is sent through a solution of a compound with a metal in it, to get this metal out of the compound and make it collect where it is wanted. When such experiments were tried, it was found that electroplating can be done.

Figure 83 shows how a notebook ring can be plated with copper. The solution of copper sulphate, although you might never guess it from its bright blue color, contains copper. As the current flows through the solution of copper sulphate, the copper sulphate is broken up, and the copper collects on the metal ring. Copper is deposited on the ring as long as the current continues to flow. This experiment would work even if a nail were used instead of the strip of copper, but the strip of copper is better. If the strip of copper were not there, the copper in the solution would soon be used up. As it is, the copper is taken from the solution and put on the ring, but, as soon as the solution loses some of its copper, it takes some copper from the copper strip. It then has as much copper in it as before. The current causes copper to be taken away from the copper strip and to be put on the metal ring.

Notice that only one cell is shown in the diagram. A strong current should be avoided. Too strong a current causes a dark brown powdery coating to form on the object to be plated.

Notice, too, that the article to be plated is fastened to the zinc, or negative, post of the cell. This is important. In the experiment shown in Figure 83, the copper plating could be removed from the ring by changing the wires so that the current flowed through the solution in the opposite direction.

An object to be plated must be thoroughly clean.

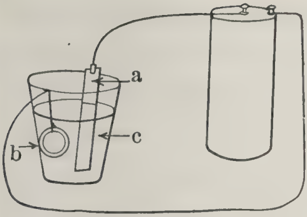


FIG. 83. COPPER PLATING
*a*, copper — *b*, object to be plated — *c*, copper sulphate solution

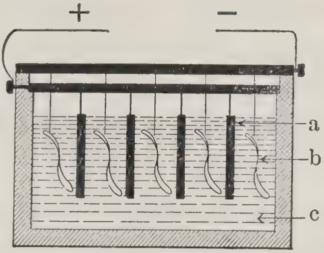


FIG. 84. SILVER PLATING
*a*, silver — *b*, spoon — *c*, solution of a silver compound

An object may look clean and yet not be clean enough to plate. Oil which does not show will interfere greatly with plating. Things to be plated are usually cleaned in a solution of acid, and are then washed in clear water to remove the acid.

In all copper plating, a solution which contains copper is used, but it is not always a copper sulphate solution. Iron, for example, can be copper-plated, but it cannot be copper-plated successfully in a copper sulphate solution. You could not copper-plate a steel notebook ring successfully in a copper sulphate solution if the ring were not nickel-plated.

If you try the experiment shown in Figure 83, you may be surprised to see how tightly the copper plating sticks to the ring. If the plating is well done, you can polish the copper without rubbing any appreciable amount of it off. If you haven't a notebook ring to plate, you might try copper-plating the handles of a pair of scissors, or some other small metal article which has already been nickel-plated. You might try copper-plating a carbon rod; carbon can be plated very successfully in a copper sulphate solution.

If you are trying a plating experiment, you must guard against short circuits. If the metal ring were to touch the copper strip in the experiment shown in Figure 83, the ring would not be well plated.

Figure 84 shows how spoons are silver-plated. Notice that several rods of silver are connected to the positive pole of the battery, and several spoons to the negative pole. The solution is made of water and a compound which contains silver.

For nickel plating a rod of pure nickel and a solution containing nickel are needed. For gold plating you would need a rod of gold and a solution containing gold.

For commercial electroplating a generator may be used instead of a battery to furnish the current. The current must be a direct current. Can you picture what would happen if an alternating current were used in an attempt to electroplate an article?

It should not be difficult for you to understand that only materials which are good conductors of electricity can be electroplated. However, a fern leaf and a wax statue and a fly and a baby's shoe have been plated, and not one of them is made of materials which are good conductors of electricity. The explanation is this: A substance which is not a good conductor may be plated if it is first coated with a thin coating of a material which is a good conductor. Powdered carbon is used for this thin coating in many cases. Suppose a little wax statue is to be copper-plated. It is covered with a thin layer of powdered carbon. The wire leading to the negative pole of the battery or generator is then connected to this carbon coating, and the statue is put in the copper-plating bath. In this way you may copper-plate a fern leaf, a dead insect, or even a baby's shoe.

## XXIV. THE PART ELECTRICITY PLAYED IN MAKING THIS BOOK

Electricity played a very important part in the making of this book, just as it does in the making of most books now printed. As you will see, it was more important in the later steps in the making of the book than in the early steps. The book was written, the drawings were made, the photographs were selected, the type was chosen, and the length of the book was estimated. With all these things electricity had nothing to do except, of course, that if it weren't for electricity the book wouldn't have been written at all.

The type was then set by means of a monotype machine. As soon as the type was set, proof was taken. This first proof, called galley proof, was read very carefully, and mistakes were corrected.

At the same time that the type was being set up, the pictures were being reproduced. Illustrations such as Figures 83 and 84 were made by the process called zinc etching. To make a zinc etching, a drawing is photographed onto a zinc plate that has been coated with a chemical preparation which is sensitive to light. The plate is then washed, and the picture appears on the plate in lines or masses of hardened chemical. The remainder of the chemical preparation with which the plate is coated dissolves when the plate is washed. The lines of the picture are further strengthened with a material called "dragon's blood." Then the plate is put into an acid bath, and the acid eats into the zinc wherever it is not protected by the chemical. The plate is etched by the acid until the lines of the picture stand up high above the rest of the plate. Proof of the picture is taken, and necessary corrections in the etching are made by a skilled engraver. The plate is then mounted on a wooden block so that it is ready for printing.

Illustrations such as Figure 85 were made by the half-tone process. If you look at this illustration through a hand lens, you will see that the picture is made up of black spots with white spaces between. In the light part of the picture, the black spots are small and are separated by wide white spaces. In the darkest parts of the picture the spots are larger and are so close together that very little white shows. To change an ordinary photograph into such a "dot picture," the original picture is photographed through a screen onto a sheet of polished copper coated with a sensitive preparation. The screen is a plate of glass ruled criss-cross with fine lines. When the copper plate is washed, the chemical preparation is washed off except from the spots which are to be black in the picture. The plate is then put into a chemical bath and the spaces which are to be white are etched into the copper. At length the black spots stand up above the plate just as the lines do in a zinc etching. The engraver then goes over the plate and makes any changes that are necessary. After this the plate is mounted.

After the galley proof was corrected and the half-tones and zinc etchings were made, the type was arranged in pages. Room was left for the illustrations. Again proof was taken, and mistakes in this page-proof were corrected. Still electricity had had nothing to do with the making of the book except to furnish light for the workmen to see their work, and to furnish the strong light needed for transferring the pictures to the copper and zinc plates.

The next step, however, was one in which electricity played a most important part. You may be surprised to be told that books are not printed directly from the type. They are printed from electrotypes. If the publishers had planned to sell only a few hundred copies of this book, they might have had it printed directly from the type. But type metal is soft metal. It has much lead in it. It wears off easily. By the time the type had been used for printing several hundred copies of the book, it would probably be worn so that some letters would be imperfect. The stereotypes from which newspapers are printed are made of type metal. In the case of a newspaper, it doesn't make much difference if some of the letters are slightly imperfect, but in a book, which one reads more carefully and which one, as a rule, keeps much longer than one does a newspaper, we insist that the printing be even and clear.

In order to get thousands of clear copies, the printing must be done from harder metal than type metal. Copper is much harder than type metal and wears much longer, but, for certain reasons, it would not be satisfactory to use copper type. It is possible, however, to make a copper reproduction of each page of type, and this is done. The following paragraphs will tell you how the copper electrotype for each page of this book was made.

The first step in electrotyping a page is to press the type for the page into a mold of soft wax. A machine is used to press the type into the mold just firmly enough so that the impression will be clear. The pressure must not be great enough to make the wax stick to the type. Every letter and every punctuation mark is pushed down into the soft wax. When the page of type is removed, there in the wax is the page of print, but the letters and punctuation marks are lowered, not raised.

This wax mold is then copper-plated. Of course, since wax is not a good conductor of electricity, it must be coated with some material which is a good conductor of electricity before it can be plated. In most cases powdered carbon is used. The workmen must be careful to see that the entire face of the mold is covered with carbon. Where there is no carbon there will be no plating.

After a thin layer of copper has been deposited on the wax mold, the mold is removed from the copper-plating bath, and the thin sheet of copper is pulled away from the mold very carefully. This sheet of copper may be anywhere from one thirty-second to one eighth of an inch thick. Of course, on the side of the sheet of copper which was toward the wax, the letters are raised just as they were on the type. This is the side of the copper sheet from which the printing is done. No printing can be done from this electrotype yet, however, because the metal is too thin. Melted type metal is then poured on the back of the electrotype to strengthen it. After the edges are smoothed off, the electrotype is ready to be used for printing.

Every page in the book on which there is any printing was electrotyped in this way. In fact, several wax impressions of the type for each page were taken, and several copper plates of each page were made. Even copper plates wear out. When one set of copper plates wears out, another is ready to use without having to set up the type again. Moreover, if necessary, two or more presses could be printing the book at the same time.

Half-tone and zinc etching plates wear out in time, too. Duplicates of all the illustrations in the book were made by electroplating, just as the electrotypes of the pages were made.

Electricity had by no means played its whole part in making this book when the pages were electrotyped and the duplicates of the zinc etchings and half-tones were finished. The press on which the book was printed was run by an electric motor. As you may know, each page is not printed separately. Several pages are locked up together and are printed on big sheets of paper. In some books you can see, by the fact that some of the folded edges have not been cut, that the pages are printed on large sheets of paper and that these large sheets of paper are then folded. In this book the edges were cut so that the folds do not show. The

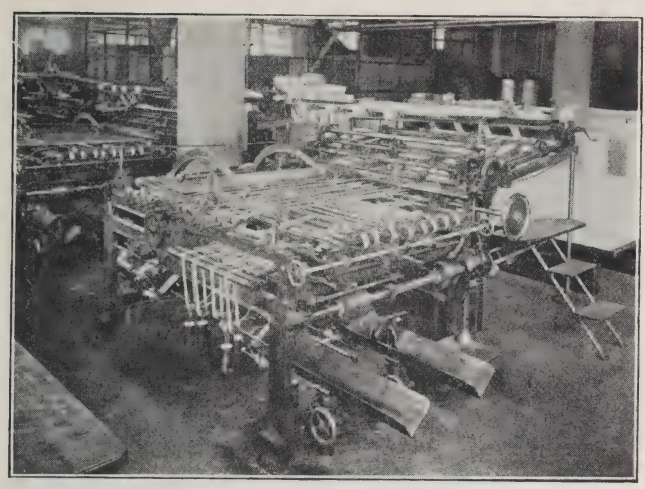


FIG. 85. A MOTOR-DRIVEN MACHINE FOR FOLDING SIGNATURES

large sheets of paper on which many pages are printed are called "signatures."

Figure 85 shows a machine which folds the signatures. This machine is run by an electric motor. The machine seems almost human. Whenever it starts to fold two signatures at a time instead of one, it stops working until a workman comes and corrects the mistake.

After the signatures were folded and placed in piles, another machine assembled the signatures for each book in order. This "gathering" machine was driven by an electric motor, too.

All the pages for one book were then stitched together by means of a heavy sewing machine like the one shown in Figure 86. It, too, was run by

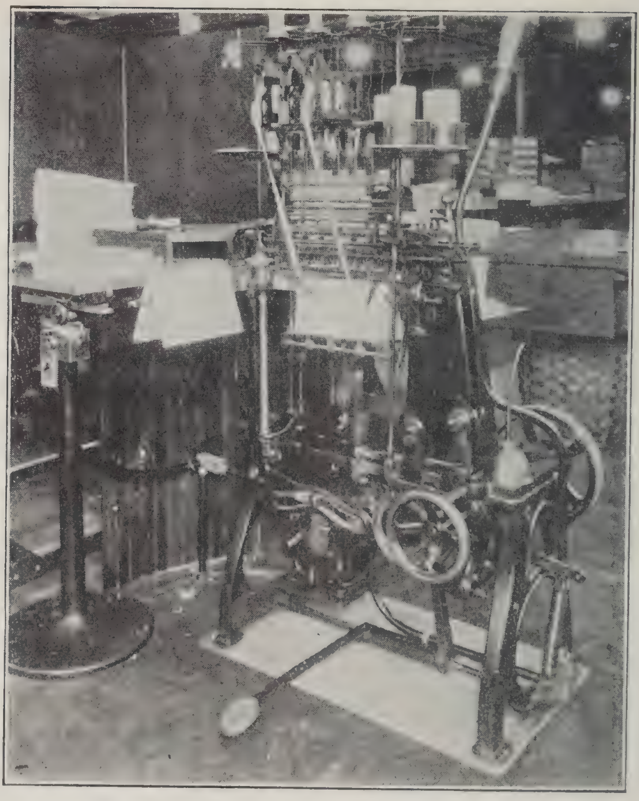


Fig. 86. A Motor-Driven Sewing Machine

an electric motor. Can you find the motor in the picture?

A piece of heavy paper was glued to the back of the book. The binding was then fastened on. This, too, was done by a machine run by an electric motor. The books were then kept in a press for a few days and were ready to be sold.

A few hundred years ago not very many people owned books of any kind. This was in the days when all books had to be copied by hand. Now there are few people in our country who haven't at least a few books. Books are cheap and plentiful. The printing press is largely responsible for this. Electricity, however, through its use in electrotyping and in running the machines which print and bind the books, has played an important part in bringing the prices of books down within the reach of all of us.

# WAYS IN WHICH DOCTORS USE ELECTRICITY

## XXV. ELECTRICITY AS THE DOCTOR'S HELPER

Doctors do not do nearly so much guessing as they used to do. If a patient with a broken arm goes to a doctor, the doctor does not have to guess how serious the break is; he can find out by having an X-ray picture taken. After the doctor has set the broken bone, he does not worry for fear he may not have set the bone in exactly the right position; he has another X-ray picture taken to show how good a piece of work he has done. If a baby who has swallowed a penny is brought to the doctor, the doctor does not guess where the penny is; he finds out by using X-rays. Perhaps the doctor thinks that a certain patient is ill because he has abscesses at the roots of his teeth. X-rays will tell the doctor whether or not he is right. Perhaps the doctor has diagnosed a patient's illness as a sinus infection. Again the X-ray will check his diagnosis. And so it goes. How often the doctors of old must have said to themselves, "If I could only see!" They couldn't see what was going on inside the bodies of their patients because light does not go readily through the materials of which our bodies are made. Doctors can both diagnose and treat diseases much better than they could thirty-five years ago, partly because they are now able to see much of what goes on in our bodies, as they were not able to before that time. Electricity deserves the credit for this, for electricity has given us the remarkable X-ray.

X-rays were first discovered by the scientist, Röntgen. Röntgen was much interested in experimenting with sending electric currents through tubes from which most of the air had been pumped. He, as well as many other scientists, had found that, when an electric current goes through such vacuum tubes, the tubes glow with a colored light. Röntgen was one day experimenting with a new vacuum tube which he had made, when he discovered, quite by accident, that his tube was not only glowing, but was giving off other rays of a mysterious kind. These rays he could not see, but when they fell on a paper coated with the chemical, barium platinocyanide, the chemical shone brightly. He found that he could cover the tube with a cardboard box so that he could not see the tube at all, and that these peculiar rays would go through the walls of the box and make the chemical-coated "screen" shine just as before. It was clear that his vacuum tube was sending out rays which could go through objects through which light could not go. X is the symbol used by mathematicians to stand for an unknown quantity. Since Röntgen didn't understand the rays which came from his vacuum tube, he called them X-rays; and, although scientists know much more about them now, they are called X-rays to this day.

Of course Röntgen tried many experiments with these strange new rays. He found that, when he held a key or some similar metal object between the vacuum tube and the chemical screen, a shadow of the key fell on the screen. Some objects, on the other hand, cast scarcely any shadow on the screen. When he held his hand between the tube and the screen, the bones of his hand showed clearly.

Other scientists who had been working with vacuum tubes had been producing X-rays with them, but these scientists didn't know it because they couldn't see the X-rays. With his chemical screen Röntgen was able to prove to other scientists the existence of X-rays, and the whole scientific world was much excited by his remarkable discovery.

Better tubes than Röntgen's are now made for producing X-rays. Figure 87 shows an X-ray tube. The X-rays leave the tube in the directions shown by the long straight lines.

As you have been told, X-rays themselves cannot be seen, but such pictures as the one shown in Figure 88 can be taken with them. It is usual but not

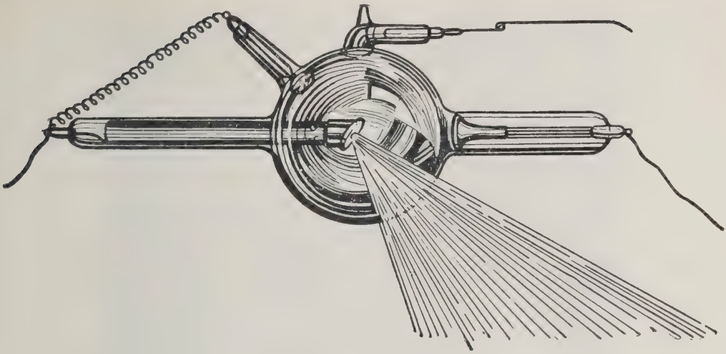
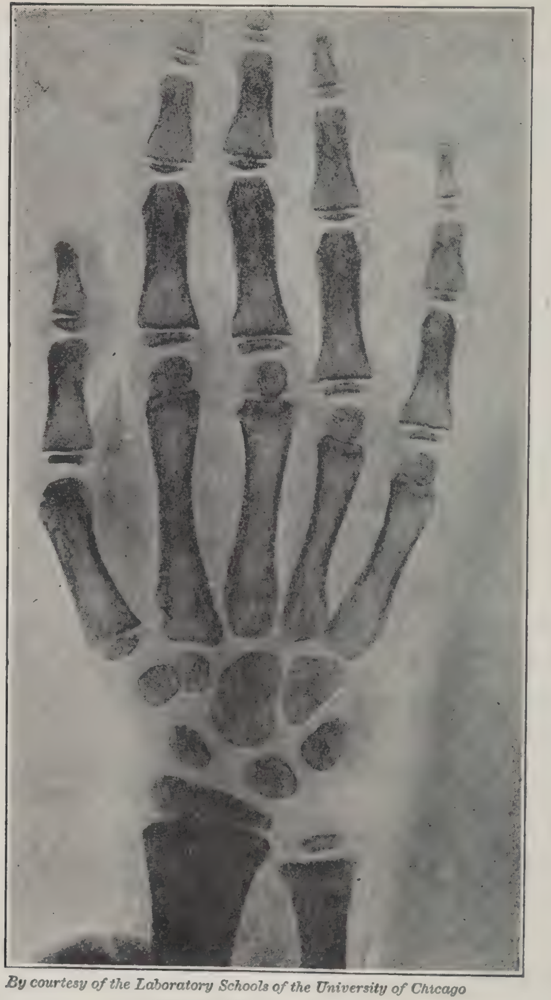


FIG. 87. AN X-RAY TUBE

necessary to take a picture in order to examine a person by means of X-rays. Instead of taking a picture, a fluoroscope may be used. A fluoroscope is a screen much like the one which Röntgen used to show the existence of X-rays. The patient is placed between the X-ray tube and the screen. From the shadow picture on the screen the doctor can tell much about what is going on in the patient's body. Doctors often use fluoroscopes in setting broken bones. They can see when they have the bones in the right position without waiting to have pictures taken. In operations to remove from the body small objects made of metal, fluoroscopes are very valuable, indeed. Of course the picture seen with the fluoroscope disappears as soon as the current is shut off from the X-ray tube.

X-rays will go through many things through which light will not go, but of course they do not go



*By courtesy of the Laboratory Schools of the University of Chicago*

FIG. 88. AN X-RAY PICTURE

through all these substances equally well. If they went through bones as easily as they go through skin and muscle, they would help doctors much less than they do. At first X-rays were not helpful in diagnosing digestive troubles, for X-rays go through the walls of the stomach and intestines so readily that no clear shadows of these organs could be seen with the fluoroscope or in a photograph. However, doctors soon found that, when patients were fed small quantities of a bismuth preparation, the bismuth which was mixed with the food in the stomach and intestines absorbed the X-rays, and a dark shadow of the digestive system appeared on the screen. By using bismuth or similar preparations, therefore, doctors are able to use X-rays in diagnosing digestive troubles.

Dentists now depend very greatly upon X-rays for help in finding out what is wrong with a patient's teeth. Having one's teeth X-rayed has come to be a very commonplace occurrence.

Not only are X-rays helpful in diagnosing diseases, but they are also helpful in treating some diseases. At first it was thought that X-rays could be used to cure such deep-seated diseases as cancer. The results of experiments with them were disappointing. These rays have, however, been found to be very helpful in treating certain less deep-seated diseases. Little by little, ways of using them effectively in treating diseases are being worked out. They may in time come to be as important in treating diseases as they are now in diagnosing them.

X-rays are not safe playthings. Many of the doctors who experimented with X-rays in the early days of X-rays were badly burned by them. One surgeon, for example, bought himself an X-ray machine. He was so proud of it that he wished all his friends to see it. Whenever one of his friends came into the office, he turned the current on, held his hand in front of the vacuum tube, and let his friend look at his hand through the fluoroscope. After he had done this many times, he found that his hand was badly "burned" by the X-rays. In fact, it was so badly burned that he never could operate again.

Now doctors have learned to protect themselves from being injured by X-rays. A doctor who has to work with an X-ray machine may protect himself by wearing gloves and an apron made of rubber impregnated with salts of lead, for lead absorbs X-rays. He may protect his eyes with lead-glass spectacles. Moreover, if a fluoroscope is being used, the doctor may have the screen so arranged that he can see the shadow picture without getting in the path of the rays.

Many uses have been found for X-rays since Röntgen first announced their discovery in 1895. The picture of an eight-year-old boy's hand, shown in

Figure 88, was taken, not by a doctor who was trying to find out what was wrong, but by a scientist who was making a study of the development of the bones in children's wrists. Notice how clearly the bones of the wrist show. Perhaps in a shoe shop you have looked through a fluoroscope to see whether or not your shoes were the right size for your feet. In some cases the workers in the diamond mines of South Africa are X-rayed when they leave the mines to find out whether or not they are carrying away diamonds either inside or outside their bodies. X-rays are used for testing many kinds of materials to see whether or not there are flaws in them. They are used in many experiments in physics and chemistry, too. They are most widely used, however, by doctors and dentists.

Although the use of electricity in producing the X-ray is probably the most important use of electricity by doctors, it is not the only one. Doctors use electric needles to remove blemishes from the skin. As you have been told, they may use electromagnets to remove bits of iron and steel from a patient's body. They may use electric vibrators for massage. They may use electricity to stimulate the growth of hair. You may have heard of diathermic treatments. This way of using electric currents in treating diseases is being more and more talked about.

One of the most interesting ways in which electricity is now used by doctors is to furnish artificial sunlight. Probably you will think at once: Why, when there is so much real sunlight, should we use artificial sunlight in curing diseases? Almost every home, even in a crowded city, has at least one window where sunlight can come in. Most of the sunlight which comes into our houses, however, must come in through glass, and the sun's rays which are most helpful in curing disease cannot go readily through glass.

As you may know, sunlight is made up of the colors of the rainbow: violet, blue, green, yellow, orange, and red. The violet and blue rays are much more important in treating most diseases than the yellow and red rays are. There are also in sunlight ultra-violet rays which we cannot see, but which scientists have proved exist. They, too, are helpful in treating certain diseases. Violet and ultra-violet rays do not pass through glass readily. Consequently the sunlight which comes into our houses through ordinary window glass has had its "curing" powers greatly reduced. Moreover, the smoke and dust in the air of cities serve as screens to shut off the violet and ultra-violet rays. Electric lights give off the same helpful rays which the sun gives off. When we use electric lights in our houses, most of these rays do not reach us because they cannot get through the glass bulbs. Fortunately violet and ultra-violet rays can go through quartz. Quartz looks much like glass, but doesn't act the same way. Electric quartz lamps have been devised in which the rays from the electric lamp are made to shine through quartz. Doctors have found these quartz lights excellent substitutes for sunlight. Moreover, they can be used summer or winter, on clear days or cloudy days.

If you have ever had a quartz light treatment, you may have noticed the peculiar light given off by the quartz lamp. Everything looks much greener or bluer than it does in sunlight. This is because the orange and red rays have been removed from the light of the electric lamp. The red rays are the heat-producing rays. To keep the patient from being burned by the light, the light is made to pass through a liquid which absorbs the red and orange rays, and allows only the rays from the blue-violet end of the spectrum to pass through. In some cases mercury lamps, electric lamps which give off no red rays, are used to furnish the light.

Quartz lights are especially valuable in treating skin diseases and such children's diseases as rickets. If you could see how fast children with rickets improve when the light from a quartz lamp is allowed to fall upon them for a few minutes each day, you would be convinced that electricity is a very valuable doctor's assistant, indeed.

# SENDING MESSAGES BY MEANS OF ELECTRICITY

## XXVI. ELECTRICITY AS A MESSENGER

When Lincoln was elected President of the United States on November 6, 1860, it was very important that the news reach California in the shortest possible time. Early news of the result of the election would do much to quiet the political disturbances there. The fastest way of sending word of the result from the east to the far west was by means of the "pony express." The pony express carried mail from St. Joseph, Missouri, to San Francisco. At each station along the way fresh horses were ready for the riders, and there was little delay. The pony express was able to carry messages across this fifteen hundred miles of mountain and plain in little more than eight days. Compared with the twenty or more days which it had taken to send a message to California before the pony express was started, this was very fast indeed. Only eight days after Lincoln was elected, the people of far-away California received the news.

When Lincoln was reëlected President on November 8, 1864, it was possible to send the news from the east to California in less than a minute; for, between the times of Lincoln's first election and his second one, electricity had been set to work carrying messages across the Great Plains. The Pacific telegraph line was finished in October, 1861. At the time of Lincoln's first election, electricity was being used for sending messages in the eastern portion of the United States, but not until the fall of 1861 was it possible for electricity to carry a message all the way across the continent. A minute instead of eight days! Compared with electricity, the pony express was very slow.

For thousands of years men have experimented with ways of getting messages quickly from one place to another. One of the earliest ways was to send a fleet runner. History is full of stories of brave men who risked their lives to carry important messages.

Many ways have been found of sending written messages quickly from place to place. Carrier pigeons, riders on fast horses, and express trains play their parts in message carrying. Now airplanes are able to carry messages for long distances more rapidly than riders, runners, express trains, or birds. If you have written a message and wish the actual paper with the message on it to be carried to a distant destination, an airplane is the fastest messenger you can use; but even an airplane traveling two hundred miles an hour is slow compared with other ways we have found of sending messages.

Hundreds, perhaps thousands, of years ago, the natives of Africa learned to use tom-toms in communicating with one another. The sound of the tom-toms could be heard more than a mile away, and codes were used so that communication could be carried on over that distance easily. Using tom-toms was much faster than sending a runner with the message, for sound waves travel through the air at the rate of about eleven hundred feet a second. A mile in five seconds — what runner or rider or airplane or express train could go so fast?

We still use sound as a messenger. In one mining town, for example, a whistle blows three times at seven o'clock in the morning if the mine is to work that day. Sirens and bells are used to give such signals, too. Sound waves, however, are not good messengers when it comes to sending messages many miles. As they travel out in all directions, sound waves become weaker and weaker until finally they die out altogether. It is ridiculous to think of sending a message from New York to California by means of bells or sirens or tom-toms.

Light is an even faster traveler than sound. Light travels at the almost unbelievable rate of about 186,000 miles a second. Light has been used as a means of communication for years and years and years. You may remember that Paul Revere read from lanterns on the church tower the message which started him on his famous ride. The Romans used great torches for signals. The Scottish chieftains sent runners with torches over mountain and hill to summon the members of the clans for warfare. Soldiers sometimes use mirrors called heliographs for flashing signals.

Wigwagging is a common way of sending messages. In wigwagging, communication is carried on by holding flags in various positions. If you are a Boy Scout, you probably have practiced wigwagging. Here again light is the messenger. Perhaps you do not see how. Suppose a soldier sending a message in this way is standing on the top of a hill. He holds his flags in a certain position. The soldier to whom he is signalling is standing, we shall suppose, on a hill two miles away. The reason the soldier on the second hill sees the flags is that light from the sun falls on the flags and is reflected by them. Some of this light reaches the eyes of the soldier on the second hill, and he sees the flags. The only thing which travels from the one hill to the other is light. Since light travels about 186,000 miles a second, the second soldier sees the flags at almost exactly the time the first soldier holds them up. If anything interferes with the light which travels from the first soldier's flags to the second soldier's eyes, the second soldier may not see the flags at all.

The Indians sent messages with columns of smoke. They held blankets over a smoldering fire and then removed them when they wished the smoke to show. In this way they could spell out messages with the smoke puffs. Of course it was the light reflected from the smoke which really carried the message to the person for whom it was meant.

Perhaps the best method ever devised for using light as a messenger was the semaphore system. A semaphore is a signal post with projecting arms. Semaphores somewhat like those you may have seen at country railway stations were used in England and France and Russia as well as in this country before it was found that electricity could be used as a messenger. The arms of a semaphore were arranged in a certain way for each letter. In this country the Colles system of semaphores was in use. By means of this system eighty-four letters could be sent in five minutes to a station ten miles away. The man who invented this system figured that, if eighty-four letters could be sent ten miles in five minutes, it should be possible to send one letter twenty-six hundred miles in fifteen minutes.

Although light is a very fast messenger, it is by no means a perfect one. There are many things which interfere with its traveling from place to place. For one thing, it travels in straight lines. It doesn't bend to get around buildings or to get past trees or over hills. Moreover, the smoke and fog in the air interfere with its traveling. Consequently it does not travel far here on the surface of the earth. You do not expect to see things that are a hundred, or fifty, or, in most cases, even ten miles away. This meant that semaphore stations had to be placed every few miles in a semaphore system. The operator sending the message arranged the arms of his semaphore. The operator at the next station a few miles away saw the first semaphore through his glasses and read the message. Then with his semaphore he sent it on to the next station.

In no system in which light was used as a messenger could the stations be very far apart. Even when the stations were close together, many of the signal systems were not usable at night. Fog, rain, smoke, and snow were likely to interfere with the journey of the light between stations, too. When the Duke of Wellington was fighting the French, this message was sent by semaphore from Portsmouth to London: "Wellington defeated." All London was thrown into a panic. Several hours later two more words of the message were received. They were: "the French." Do you see what a difference these two words made in the meaning of the message? A fog at Portsmouth had interfered with receiving the whole sentence.

The semaphore systems were soon given up after it was found that electricity could be used as a means of communication. From the early days of the use of electricity as a messenger to to-day, electricity hasn't had a rival as a message carrier. Electricity will carry a message for hundreds or even thousands of miles. It will travel by night as well as by day. In most cases smoke and fog and stormy weather do not interfere with it. It will travel along wire roadways provided for it or it will serve as a messenger without such pathways.

From time to time new ways of using electricity as a messenger have been found. Now there are four great systems for sending messages by electricity: the telegraph, the submarine cable, the telephone, and radio. Any one of these ways would be enough to convince us that, as a messenger, electricity cannot be surpassed.

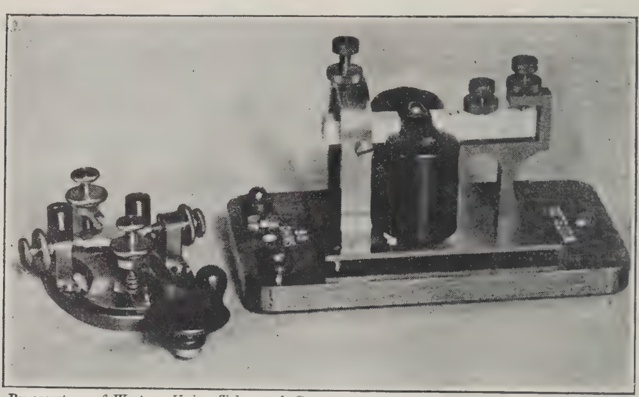
When the Republic of the United States kept on adding more and more territory to itself, many people of other countries thought that our country was trying an experiment which was bound to fail. "It is all very well for a little country like Switzerland to be a republic," they thought, "but a republic can't be very large. Think of the days and days it would take representatives to go from the far west to Washington. Think, too, of the long time it would take a representative to get word to the people who elected him about the important questions under discussion."

These people who prophesied that the Republic would fail because of the size of the country could not foresee the great transcontinental railway lines, and the use of electricity as a messenger. The present success of our experiment in government is due in part to the sending of messages by electricity.

## XXVII. THE TELEGRAPH

The first practical device invented for sending messages by electricity was the telegraph. The word "telegraph" comes from two Greek words, one of which means "far away" and the other of which means "write." The first telegraph receiving instruments did write the messages in dots and dashes on moving strips of paper, and at large stations recording instruments are used to-day, but very many operators now read telegraphic messages by sound. The instruments used in a simple telegraph circuit are the sounder and the key. These two instruments are shown in Figure 89. To make a practice set, the key and sounder are connected with a cell in a circuit similar to the circuit shown in Figure 23. Of course, in a regular telegraph line there would be at least two stations, with a key and sounder at each station.

The key is a device for making and breaking the circuit. It serves the same purpose that an ordinary push-button serves, but it is much more care-



*By courtesy of Western Union Telegraph Company*

FIG. 89. TELEGRAPH KEY AND SOUNDER

fully constructed. Notice in the picture of the sounder the U-shaped electromagnet and, above the poles of the magnet, a soft iron armature attached to a brass or aluminum bar, which is pivoted so that it can move up and down. When a current flows through the electromagnet, the iron armature and the bar to which it is attached are pulled down toward the poles of the magnet. A set-screw in the brass or aluminum bar hits the metal support and makes a click. When the circuit is broken, the magnet loses its magnetism, and a spring pulls the armature and the bar away from the magnet. When the metal bar is pulled up, the end of it strikes another set-screw and makes another click. A trained operator recognizes a difference in the sound made when the armature is pulled down and that made when it is pulled up.

Messages are sent in a code which consists of dots and dashes. If the sending operator holds the key down for a very short time, the current of electricity flows through the magnet for a short time, and there is only a very short time between the click made when the armature is pulled down and that made when the armature is pulled up. The receiving operator recognizes this as a dot. If the sending operator holds the key down for a longer time, there is a longer time between the two clicks. The receiving operator recognizes this as a dash.

There are two telegraph codes in common use: the American Morse Code, and the International Morse Code, or Continental Code. The chief advantage of the Continental Code over the American Morse Code is that there are no "spaced" letters in the Continental Code. *C*, *r*, *y*, *o*, and *z* are spaced letters in the Morse code. In rapid sending it is hard to tell the difference between the spaces of spaced letters and the spaces between letters. *O* is likely to be read as double *e*, *c* as *i e*, and *r* as *e i*. *Y* might be read as double *i*, and *z* as *s e*. The two codes follow:

| American Morse | | Continental or International Morse |
|---|---|---|
| A | · – | · – |
| B | – · · · | – · · · |
| C | · ·  · | – · – · |
| D | – · · | – · · |
| E | · | · |
| F | · – · | · · – · |

| | American Morse | Continental or International Morse |
|---|---|---|
| G | --. | --. |
| H | .... | .... |
| I | .. | .. |
| J | -.-. | .--- |
| K | -.- | -.- |
| L | — | .-.. |
| M | -- | -- |
| N | -. | -. |
| O | . . | --- |
| P | ..... | .--. |
| Q | ..-. | --.- |
| R | . .. | .-. |
| S | ... | ... |
| T | - | - |
| U | ..- | ..- |
| V | ...- | ...- |
| W | .-- | .-- |
| X | .-.. | -..- |
| Y | .. .. | -.-- |
| Z | ... . | --.. |
| 1 | .--. | .---- |
| 2 | ..-.. | ..--- |
| 3 | ...-. | ...-- |
| 4 | ....- | ....- |
| 5 | --- | ..... |
| 6 | ...... | -.... |
| 7 | --.. | --... |
| 8 | -.... | ---.. |
| 9 | -..- | ----. |
| 0 | —— | ----- |
| . | ..--.. | .. .. .. |
| , | .-.- | .-.-.- |
| ? | -..-. | ..--.. |

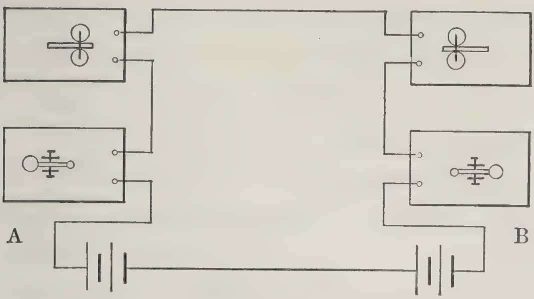


FIG. 90. A TWO-STATION TELEGRAPH LINE

Figure 90 shows a two-station telegraph line. This is such a line as you might set up between your home and your neighbor's. Let us suppose that operator at Station A wishes to send a message to Station B. Since there is a key at each station, there are two breaks in the circuit. When the operator at Station A presses down his key, there is still a break in the circuit at B and no message can be sent. The operator at B may hold down his key. That will enable the operator at A to make and break the circuit. But, of course, having to hold down the key while receiving a message would be a great nuisance, and, moreover, the operator at B would have no way of knowing when the operator at A wished to send a message to his station. To avoid this difficulty, each key is provided with a switch. Can you find the switch in the picture of the key in Figure 89? This switch may be moved over so that it closes the circuit. When an operator is not sending a message, he leaves the switch closed so that his instrument is ready to receive messages. When he wishes to send a message, he opens the switch and is then able to make and break the circuit with his key.

Many stations may be on the same line. In a simple circuit, similar to the one shown in Fig. 90, the switches are closed at all the stations except at the one where the operator is sending a message. When no message is being sent, all switches are closed, as a rule, and the current flows continuously. If an operator fails to close the switch after he has sent a message, it makes it impossible for other stations on the line to send messages.

In commercial telegraphy, when two stations at a considerable distance from each other are to be connected, one wire only is used to connect the stations. The ground, which is a very good conductor of electricity when moist, serves as a return wire. At each end of the line a short wire from the battery is connected to a metal plate which is buried deep enough so that the soil around it will be always moist. The ground plates used are, in most cases, at least fifteen inches square and are, in many cases, larger. A grounded circuit requires only half as much wire as a wire or metallic circuit. Since the cost of the wire, whether galvanized iron wire or copper wire is used, is an important item in the cost of building a telegraph line, much expense is saved by using a grounded

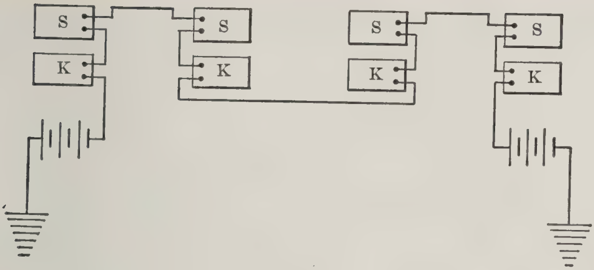


FIG. 91. A GROUNDED CIRCUIT

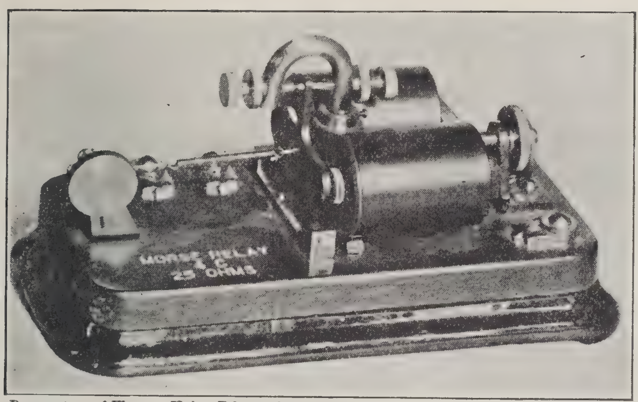
circuit. Moreover, if the ground connections are good, a grounded circuit offers less resistance than a metallic circuit, and fewer batteries are needed. Using the ground for one wire also reduces the cost of keeping a line in order, for it reduces the number of chances for breaks to occur. For very short lines (a quarter of a mile long or less) the cost of a metallic circuit is about the same as that of a grounded circuit, and the all-wire circuit is usually better for such short distances.

When there are several stations on one telegraph line, only the stations at the ends of the line ground their wires, as the diagram in Figure 91 shows.

Why shouldn't a telegraph station ground both wires? This question is often asked. If a station should ground both wires, there would be a short-circuit through the ground, and the operator would be able to send messages only to himself.

Since a current of electricity flows almost continuously through a telegraph circuit, dry cells are never used on a commercial line to furnish the current. Dry cells wear out very quickly with continuous use and are desirable only in case a current is needed for few minutes at a time, as in a doorbell circuit. If you should set up a telegraph line and should use dry cells, you should not keep the switches closed all the time. The circuit should be a complete circuit only when messages are being sent. Gravity cells deteriorate unless they are used to produce a current continuously. They are, therefore, well-suited for use on a telegraph line. In many cases storage cells are used. At many large stations, generators are used instead of batteries.

When such a telegraph line as the one shown in Fig. 91 is many miles long, getting a current which is strong enough to operate all the sounders on the circuit is a problem. The wire on such a long line offers great resistance. Moreover, the electricity has a better chance to escape from the wires when the line is long. In wet weather much more current leaks from the wires than in dry weather. Glass or porcelain insulators are used on telegraph poles to prevent the electricity from flowing down the poles into the ground and back to the cell or generator, but these insulators do not do away with all leakage. Of course, if the current is not strong enough to operate all the sounders on the line, more batteries might be used, or a stronger current might be had



*By courtesy of Western Union Telegraph Company*

FIG. 92. A TELEGRAPH RELAY

from the generator, but the leakage would be proportionately greater. Relays make it possible to send messages for long distances without using a powerful current.

A relay, as you can see by examining the picture in Figure 92, is much like a sounder. Just as in the sounder, there is an electromagnet, but it is placed horizontally in the relay. In front of the poles of the magnet, there is a small plate of iron which is held away from the magnet by a delicate spring. This small iron plate corresponds to the armature of the sounder. A relay, which is a much more sensitive instrument than a sounder, is put in place of the sounder in a long line. When a current flows through the magnet of the relay, the small iron armature is pulled toward the magnet. It hits a stop. When

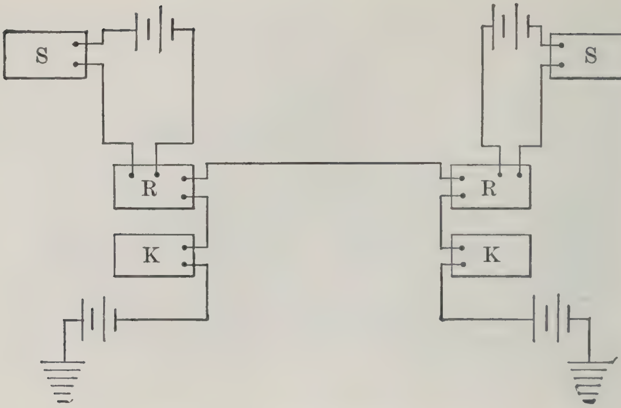


Fig. 93. A Circuit with Relays

the circuit is broken, the spring pulls the armature back, and it hits another stop. The armature is so light that it makes very little sound when it strikes the two stops. It is, therefore, very difficult to read messages by sound from a relay. However, connections are made so that when the armature of the relay is pulled over toward the magnet, it acts as a key and closes a local circuit in which a battery and sounder are connected. Notice the local circuits in Figure 93. When the current ceases to flow through the relay, the armature is pulled away from the magnet, and the local circuit is broken. Thus a weak current can be made to operate the relay and send a strong current through the sounder. Usually gravity cells or storage batteries are used in the local circuit, and storage batteries or a generator on the main line. The key must, of course, be in the main line, not in the local circuit.

A telegraph circuit like the one shown in Figure 93 may seem somewhat complicated, but most important telegraph lines are even more complicated, for they are arranged so that two or more messages can be sent at one time over one line. One of Edison's important inventions is the arrangement of telegraph wires so that two messages can be sent over a line at the same time. The messages are sent in opposite directions. For example, if Station A and Station B are connected by a telegraph line, Station A can send a message to Station B at the same time that it is receiving a message from Station B. The two messages do not interfere with each other. This is called duplex telegraphy. Other systems of duplex telegraphy are in use also. Edison invented the quadruplex system, too. By means of it four messages, two in each direction, can be sent at the same time over one wire. Practically every important telegraph line is now arranged for duplex telegraphy, and many for quadruplex. Even multiplex telegraphy is now possible. One system in common use has made it possible to send eight messages at once over a single wire.

Much more complicated telegraph instruments than the key and sounder and relay are in use at many large stations, too. The first telegraph receiving instruments, as you have been told, wrote the messages in dots and dashes on moving strips of paper. These recording instruments were soon given up for the simpler sounders. Now, in order to increase the speed at which messages can be sent, automatic devices are once more being used to record telegrams, and other automatic devices are being used in place of the key to send messages. With an ordinary key and sounder, a good operator can send and receive telegrams at the rate of from thirty to forty words a minute. With the new automatic machines, messages can be sent and received at the rate of more than a hundred words a minute.

Many very interesting automatic sending and recording instruments have been invented. In one system which is being widely used at present, the sending operator types the message to be sent. His typewriter, instead of printing letters, punches dots and dashes in a paper ribbon. This paper ribbon is then sent through an automatic sending machine. The perforated paper strip serves to make and break the circuit and send the message. At the other end of the line, the receiving instrument punches dots and dashes in a moving strip of paper. This strip of paper is sent through a special kind of typewriter, and the message is typed and is ready to be gummed to a telegraph blank for delivery. Perhaps you have received or seen a telegram which had the message typed on narrow strips of paper pasted on the telegraph blank. When you see such a telegram you may know that the message was received by one of the automatic receiving sets. Of course the automatic sending and receiving instruments are in use only at those stations where a big volume of business is handled. At the smaller stations throughout the country, the key, sounder, and relay are still in use.

To-day there are approximately six million miles of telegraph line in operation in the world. The wire used in these lines would reach two hundred forty times around the earth at the equator. About one fourth of the world's telegraph mileage is in the United States. Over the telegraph lines of the world millions and millions of messages are sent in the course of a year. The Western Union Company, the largest telegraph company in the United States, reports that it handles more than a hundred million messages a year in addition to the messages which are sent under special railroad contracts. The Central Telegraph Station in London handles about one hundred fifty thousand telegrams a day. Sometimes, when the British Parliament is in session, the news sent out in one day from this station amounts to five hundred thousand words. Most of the news, with the exception of local news, which newspapers print is received by telegraph. Is it any wonder that in large telegraph stations automatic sending and receiving machines have been put into use? If it were not for these automatic machines, many more operators would be needed in the large stations. If it were not for the duplex, quadruplex, and multiplex systems, very many more telegraph lines would be needed to handle the great volume of business.

For many years it has been possible to send messages by telegraph, but only recently has it been possible to send pictures by telegraph. Not only has much of the news which you read in the daily paper been telegraphed in to the newspaper offices, but some of the pictures you see in the paper may have been telegraphed to the newspaper, too. Sending a picture by telegraph is not a very simple process; for this reason by no means all the pictures from afar which one sees in the papers are telegraphed pictures. Pictures are telegraphed only when there is a great hurry for them. Telegraphing a picture is made possible by the use of the material selenium. Selenium allows electricity to flow through it when light shines upon it. The stronger the light, the stronger the current which flows through the selenium. By the use of the selenium at the sending station, and by the use of a light-giving Neon tube at the receiving station, a picture at the sending station can be reproduced at the receiving station. To most people it probably seems more wonderful to send a picture by telegraph than merely to have a word message "written far away."

## XXVIII. THE STORY OF THE INVENTION OF THE TELEGRAPH

When the steamship Sully sailed from Havre for New York on the first day of October, 1832, Samuel F. B. Morse was one of the passengers on board. Mr. Morse had spent three years in Europe studying the famous pictures in the art galleries there and painting pictures of his own. He was now returning to his home in New York. Morse was at this time forty-one years old, and was fairly well known as an artist. He planned, on his return to the United States, to paint a great historical picture which he hoped would be far better than anything he had yet done.

At that time the voyage from Europe to America was a long one, and the passengers had much time for talking with one another. One day one of the passengers, Dr. Jackson, described some very interesting experiments which he had seen performed in Paris. Many discoveries had recently been made in the field of electricity, and there was a widespread interest in the subject. The electromagnet was one of the recent inventions. Dr. Jackson had a small electromagnet in his trunk and, although he did not show the magnet, he told about it and answered questions about the way in which it worked. In college Morse had been much interested in electricity and magnetism. It is not surprising, therefore, that he was much interested in these discussions about electricity and electromagnets.

Some one asked Dr. Jackson one day how long it took the current of electricity to flow through the magnet. Dr. Jackson replied that electricity travels so fast that it would go through the coils of his magnet almost instantaneously. During this discussion Morse suddenly suggested that it ought to be possible to use so fast a traveler for sending messages.

The idea of using electricity to send messages almost instantaneously from one place to another appealed to Morse as being, not a wild dream, but a practical suggestion. Apparently the electric current could be made to go from one place to another almost instantaneously. However, you can't see an electric current flowing through a wire. What was needed, if electricity was to be used as a messenger, was a way of enabling a person to see when an electric current was flowing through a wire. Morse decided that an electromagnet might be used to show when a current was flowing. He spent most of his time during the remainder of the voyage planning an electromagnet telegraph.

By the time Morse landed in America he had the plan for the electromagnet telegraph fairly well worked out. As he left the boat he said to the captain, "Well, Captain, should you hear of the telegraph one of these days as the wonder of the world, remember that the discovery was made on the good ship Sully."

Morse's friends were much surprised to find that he was now more interested in working out his new plan for a telegraph than he was in painting a great historical picture. However, he had no money for the apparatus he needed, and for two or three years he had to spend most of his time painting and teaching. He could work upon his invention only during his few spare hours.

It is hard for us to imagine what a task it was for Morse to try out his plan. He could not buy the apparatus he needed and had to find ways of making it by hand. At that time electromagnets were not for sale as they are now. Morse had to get a small rod of iron from the blacksmith and have him bend it into the shape needed. Then this iron core had to be wound with insulated wire. Insulated copper wire was not to be had. Even bare copper wire could be bought only in small quantities and at a very high price. Morse bought the copper wire he needed, and wound it by hand with cotton thread. Other parts of the instruments were hard to get, too. Batteries had to be made.

The first telegraph set was completed in 1835. This first set certainly didn't look much like our sets of to-day. It was a very clumsy affair. The electromagnet it contained caused a pendulum to move back and forth as the circuit was made and broken. A pencil at the bottom of the pendulum made marks on a moving strip of paper. If the pencil touched the paper for a very short time, a dot was made on the paper; if it touched it for a longer time, a dash was made. Since this instrument could record only dots and dashes, an alphabet made up of dots and dashes was worked out.

In spite of the crudeness of this first instrument, it worked satisfactorily. At first Morse did not plan to use a key. During the early experiments, the messages were sent by means of a very complicated device. The words of the message were first set up in a special kind of type. This type was then used to make and break the circuit automatically. After a short trial, however, this automatic system was abandoned and a key much like the one now used was substituted.

Morse wished, before he showed his instruments to the public, to prove that it would be possible to send messages for long distances with them. He realized that, when the receiving station was a long way from the sending station, the current which reached the receiving station might be so weak that the magnet would not work satisfactorily. To make it possible to send messages long distances he planned and built a relay. Some people consider the relay the most remarkable part of Morse's telegraph.

Even after he had built his relay, he could not show his whole scheme for a telegraph line. To make the telegraph a practical invention, every station should be able to both send and receive messages. To show his whole plan he needed at least two sets of instruments. For two years Morse worked at improving his original instruments and building a second set.

Finally, in 1837, five years after his voyage on the Sully, he asked some of his friends and acquaintances into his studio to see his telegraph. All of them were convinced that it was a really practical invention. Alfred Vail was one of those who saw the telegraph at this time. He was so greatly impressed with it that he offered to supply the money and the materials needed for carrying the work further. Vail was a skillful mechanic and was a very great help to Morse from that time on. He became Morse's partner.

Morse then decided to get a patent upon his invention. He applied for a patent in this country and went abroad to try to get patents in some of the foreign countries. The trip abroad was very discouraging. When he reached England he found that two scientists there, Wheatstone and Cook, were already patenting an electric telegraph. It was not like Morse's telegraph, but it was possible to send messages with it. When Morse found that he could not get a patent in England, he went to France, but he was no more successful there. He even had to wait until 1840 to get a patent from the United States Government.

By this time Morse had done all that he cared to do with the telegraph without Government help. He wished the Government to give the money needed for building a telegraph line between some two cities. He showed the telegraph to the members of Congress, and many of them seemed to think it a great invention. It was not, however, until three years later that the Government voted him the money for building the telegraph line. Those three years were very discouraging ones. Most of Morse's friends began to fear that the telegraph would never be a commercial success. Many people objected to having the Government invest money in any such "wild" scheme. The Postmaster-General said that the Government might just as well spend money in studying mesmerism. But Morse did not give up hope that the Government would give him the help he needed.

February 23, 1843, was a momentous day in the history of the telegraph. It was the last day of the session of Congress. A bill appropriating thirty thousand dollars for constructing a telegraph line from Washington to Baltimore had passed the House of Representatives, but had not yet been voted upon in the Senate. At ten o'clock that night there were many bills yet to be considered by the Senate, and only two hours remained. Morse was told by one of the Senators that it was useless for him to stay in the Senate Chamber, that his bill, even if brought up for a vote, would surely be defeated. Morse went to the hotel and prepared to return to New York next day. You can imagine that he was very much discouraged. He had worked for ten years on the telegraph only to have it turned down as an invention of no importance. Morse tells that after buying his tickets for New York he had only thirty-seven and a half cents left. The next morning, to his great surprise, he was greeted with the news that the appropriation bill had passed.

Morse, of course, did not return to New York that day. He began immediately the task of constructing the telegraph line. Unfortunately Morse's first scheme was to put the wires underground. After spending more than half the money in laying the underground wires, this scheme had to be given up, and the wires were put on poles. This was a much cheaper and more satisfactory method. Glass insulators were used to prevent the electricity from flowing down the poles into the ground. The line was finally in working order. A battery of one hundred cells furnished the current. The relays weighed one hundred fifty pounds apiece and had to be adjusted very frequently.

Miss Elsworth, who had brought the news to Morse that Congress had finally passed the appropriation bill, was asked to select the first message to be sent over the new line. The message she chose was, "What hath God wrought?" This message, sent from Washington, was received in Baltimore. The telegraph was a success.

Improvements were made very soon. Smaller magnets with finer wire were used in the relays. Fewer cells were used to furnish the current. Better glass insulators were invented.

Soon after the line was completed, a convention was held in Baltimore to nominate candidates for President and for Vice-President. The convention nominated Silas Wright, who was in Washington at that time, for Vice-President. Mr. Vail telegraphed the news to Washington. Morse told Mr. Wright of his nomination. Mr. Wright asked Morse to telegraph back that he declined the nomination. Mr. Vail delivered this message to the convention, but the members refused to believe that a message could have been sent to Washington and an answer received in so short a time. A committee went to Washington to see Mr. Wright in person. The committee found that the message had been correct. This incident called the attention of many people to the new telegraph line.

On April 1, 1845, the line was opened for public use; and regular operators were appointed. The charges decided upon were one cent for every four letters. The receipts for the first four days were one cent. A man who had no money with him but a twenty-dollar bill and one cent wished to see the telegraph work free of charge. This was against orders. He then asked for one cent's worth of telegraphy. A code or list of signals had been made out by means of which some messages could be sent more quickly than if each word were spelled out. In this code "4" stood for the question, "What time is it?" The operator sent the signal "4" to Baltimore. Baltimore answered, "1." That meant that it was one o'clock. Although this was really only one half cent's worth of telegraphy, the man paid his cent and departed. This one cent was the only revenue for four days. On the fifth day the receipts amounted to twelve and one half cents. On the eighth day the receipts rose to one dollar and thirty-two cents.

Morse then offered to sell the telegraph to the Government. Although many people now admitted that the telegraph was immensely valuable, the Government feared that the income would never equal the expenses of keeping the lines in order, and decided not to buy it.

Private companies were soon formed. These companies proved that a telegraph system could be operated at a profit. Many new lines were built, not only in this country, but in Europe, too. Morse lived to see more than one hundred thousand miles of telegraph line in this country alone and to know that the world recognized him as one of the great inventors of his time.

## XXIX. MAKING A TELEGRAPH SET OF YOUR OWN

If you understand how telegraph instruments work, planning and making a telegraph set is not difficult.

For the telegraph sounder you need:

1. An electromagnet. The electromagnet you were told how to make on pages 113–14 would be satisfactory. If you wish your magnet to be stronger, you may use a U-shaped electromagnet. To make such a magnet, two magnets similar to that pictured on page 114 may be joined with a strip of sheet iron. The wires of the two halves of the magnet should be connected in such a way that one of the poles of the U-shaped magnet is the north pole and the other is the south pole. You can test the poles with a compass or with any permanent magnet.

2. An armature. A large nail or a rod of iron would be satisfactory. A strip of tinned iron or of sheet iron may be used instead.

3. A spring of some sort to pull the armature away from the magnet when the magnet ceases to attract

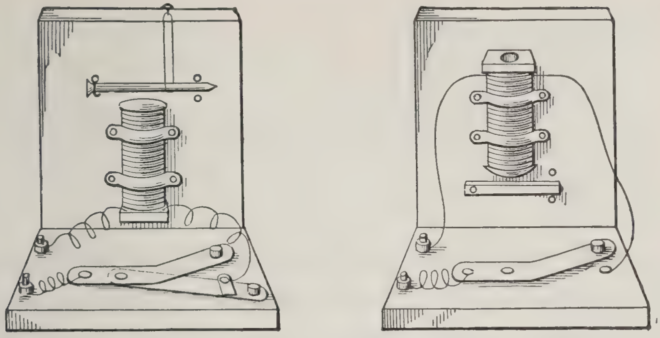


FIG. 94. TWO HOMEMADE TELEGRAPH SETS

it. Rubber bands can be used successfully for this purpose. It is possible to get along without a spring in case a strip of sheet metal is used for the armature, or in case the armature is placed below the magnet so that it falls away from the magnet of its own weight.

4. Two stops, one of which the armature hits as it is pulled toward the magnet, and the other of which it hits as it is pulled away from the magnet. Nails or screws serve this purpose satisfactorily.

5. Binding posts. Binding posts like those described on pages 115–16 are satisfactory.

6. A wooden base.

Figures 94 and 95 show three plans for putting these elements together to make a sounder. You may be able to make a better plan than any of these. In building your sounder, keep these things in mind:

1. Your stops must not be very far apart. If the

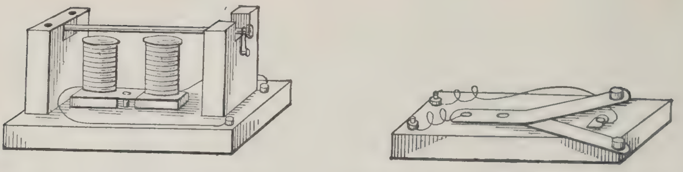


FIG. 95. A KEY AND A SOUNDER ON SEPARATE BASES

armature is pulled very far away from the magnet, the magnet will not be able to pull it toward it even if the magnet is strong.

2. Your magnet should be fastened in such a way that it can be moved up or down for a short distance. This makes it possible to lessen or increase the distance between the armature and the magnet.

Do not be discouraged if your sounder fails to work when you first try it. Probably the spring is either too tight or too loose, or the magnet needs to be closer to the armature.

The key may be on the same base with the sounder, as it is in both cases in Figure 94, or it may be on a separate base, as in Figure 95. If you plan to use your telegraph set as a practice set only, no switch is needed on your key. If you wish to use your set in a two-or-more-station telegraph line, a switch is, of course, necessary. The key shown in Figure 95 is very much like the switch described on page 115, except that a second strip of metal has been added. Notice that this piece of metal is fastened to the base in two places. This prevents its moving sideways when it is being used to send messages. The arm of the switch should be fastened in only one place.

## XXX. SUBMARINE CABLES

Electricity can be used as a messenger even if the message is to be sent across thousands of miles of ocean. Telegrams can be sent from New York to London, or from San Francisco to Tokyo, just as it is possible to send telegrams from New York to San Francisco. In fact, it is possible to telegraph from New York to any great seaport of the world. This has been made possible by the laying of cables across the seas from continent to continent. Since the wires through which the current travels under the sea are called cables, the messages sent over these wires are usually called cable messages or cablegrams.

Cable messages are much more expensive than telegrams, but they are much cheaper now than they were. It used to cost five dollars a word to send messages from New York to London; the rate from New York to London is now about twenty-five cents a word for a regular message. Special rates of only a few cents a word are given for special types of messages. Cabling is still so expensive, however, that many messages are sent in code. Of course all messages are sent in a code of dots and dashes, but in addition a single word in the message may stand for a whole sentence. For example, the business manager of a firm might have arranged with the president of the firm that the word "good" would mean, "The business is getting along very well during your absence." Code books have been published to help in sending much information in a very short message.

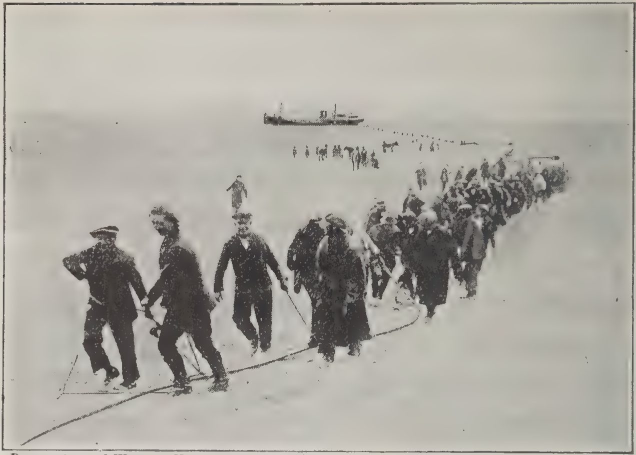
Perhaps you have seen in advertisements the cable address of the advertiser given. You may have noticed that the code address is always shorter than the real address. In an ordinary cablegram each word in the address costs just the same as any other word in the message. Consequently it is an advantage to shorten the address whenever it is possible. Newspapers are the heaviest users of the cable. Their messages are skeletonized; that is, only the important words are given.

It is not difficult to understand why cable messages are more expensive than telegrams. The equipment needed for telegraphing across the ocean is much more expensive than that needed for telegraphing on land.

For many of the telegraph lines on land, bare iron wire is stretched from pole to pole. For telegraphing across the sea such wire would not do at all. In the first place, the wire to be laid at the bottom of the sea must be heavily insulated because salt water is a fairly good conductor of electricity. In addition, the cable must be strong enough so that it will not be broken easily by sharp rocks or dragging anchors or swordfish. It must be strong enough so that it will not break of its own weight as it is being lowered from the boat into its place on the bottom of the sea.

The copper wires through which the current travels are very small in proportion to the size of the cable. These wires are very well protected. Gutta-percha and jute are used as insulators. Gutta-percha, moreover, is waterproof. Iron wires strengthen the cable so that it will not break easily. Brass tape is wound around as a further protection. A cable is very heavy. The cable used in the deep sea weighs from a ton to a ton and a half a mile. The cable near the shore must be stronger because there is greater danger of breakage there. The cable used near shore weighs from ten to thirty tons a mile. Figure 96 gives you some idea of the work involved in laying a cable. As the caption tells you, the men are pulling ashore the end of the world's fastest cable.

Even after the cable is laid, the cost of keeping it in repair is great. A cable lying in the ooze of the bottom of the sea is by no means safe even if it escapes being broken by sharp rocks or dragging anchors. Sometimes whales get caught in a cable and damage it greatly. Much more often it is injured by small plants and animals. A little shellfish called

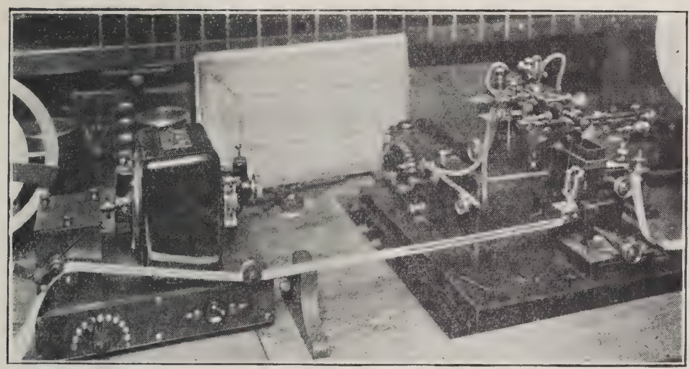


*By courtesy of Western Union Telegraph Company*

FIG. 96. PULLING ASHORE THE END OF THE WORLD'S FASTEST CABLE

the teredo is especially harmful. It bores into the gutta-percha, and may expose the wires. In this way short circuits may be caused. The brass tape used in the newer cables is a device for preventing the teredo from doing a great amount of damage.

Not only is the cable expensive and the cost of keeping it in repair great, but the sending and receiving instruments are expensive, too. Ordinary sounders cannot be used in telegraphing across the ocean. The wires are so long, and the effect of the gutta-percha insulation is such that more sensitive instruments than sounders or even relays must be used. The receiving instrument used is called a siphon recorder. Figure 97 shows a picture of such a recorder. It is very much more complicated than



*By courtesy of Western Union Telegraph Company*

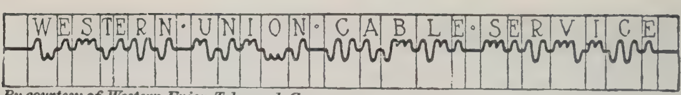
FIG. 97. A SIPHON RECORDER

a sounder. This instrument writes the messages on a moving strip of paper. Figure 98 shows a part of a cable message as it is written by one of these siphon recorders. Can you figure out how the operator can tell dots from dashes?

One dry cell doesn't furnish a very strong current. You can imagine, then, that the current from a cell the size of a thimble would not be very strong. The siphon recorder is so sensitive that a message was once sent across the Atlantic by means of a current furnished by a wet cell made in a thimble.

It is now possible to send two messages at once over a cable, one in each direction.

More than twenty cables have been laid across the Atlantic Ocean. Not all of those that have been laid are in operation now. Some of them have broken or have become defective and have not been re-



*By courtesy of Western Union Telegraph Company*

Fig. 98. A Cable Message

paired. Laying cables across the north Atlantic Ocean has been made easier by the fact that the bottom of the sea between Newfoundland and Ireland is fairly level, and is much higher than the greater part of the ocean floor. It is called "telegraph plateau." There is no "telegraph plateau" in the Pacific Ocean, and the ocean floor is rocky and mountainous in most places. Moreover, the Pacific Ocean is wider and deeper than the Atlantic. It is not surprising, therefore, that there are fewer cables across the Pacific. In the whole world more than three hundred thousand miles of cable have been laid.

In spite of the growing importance of radio, cables are still very important means of sending messages from continent to continent. The fact that one of the first things the Allies did during the world war was to cut the cables to Germany shows how important cables are thought to be. Because of the cables, countries which used to seem far away now seem to be our near neighbors. When a message can be sent by cable from New York to London in less than a minute, it is almost as if space had been destroyed and the earth were smaller than it used to be.

## XXXI. THE LAYING OF THE FIRST ATLANTIC CABLE

By 1850 the importance of the telegraph in sending messages from one part of the country to another was fully recognized. Papers in New York could print the occurrences of the day in Washington, Philadelphia, and many other cities of the United States along with the local news. News from Europe was still very slow to reach this country, however, because it had to be brought by boat. The arrival of a steamer from Europe was awaited with great excitement because it would bring word of the happenings abroad.

In 1850 a bishop who lived in St. John's, Newfoundland, suggested a way of getting news from the ships at the earliest possible moment. His idea was that, if the telegraph system of the United States were extended to St. John's, ships which passed there could drop off packets containing the important news. This could then be telegraphed far and wide. As you can see from the map in Figure 99, St. John's is much nearer Europe than is Halifax, which was then the easternmost telegraph station on the American side. This scheme of telegraphing the news from St. John's would shorten by two full days the time needed to get a message from Europe.

Perhaps Mr. Gisbourne, a man who had had much experience in building telegraph lines, read this sug-

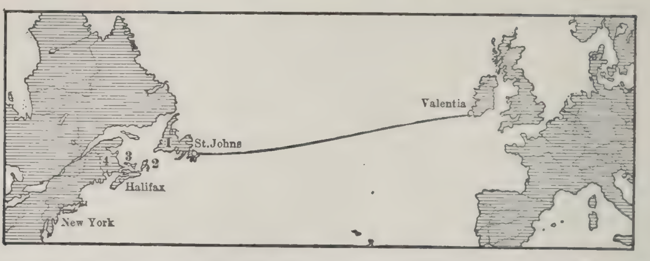


FIG. 99. MAP SHOWING THE LOCATION OF THE FIRST ATLANTIC CABLE
1, Newfoundland — 2, Cape Breton Island — 3, Prince Edward Island — 4, New Brunswick

gestion. At any rate he saw that it would be a good plan to connect St. John's with the telegraph system of the United States, and he set to work to carry out this project. He realized that building a telegraph line to St. John's would not be an easy task. It would mean not only the building of a telegraph line from St. John's to the opposite side of Newfoundland through four hundred miles of wilderness and forest, but also the laying of a cable under the Gulf of St. Lawrence from Newfoundland to Cape Breton Island. It would mean, too, the laying of two short cables, one from Cape Breton Island to Prince Edward Island, and a second one from Prince Edward Island to New Brunswick. Cables, he knew, were very expensive.

The Government of Newfoundland encouraged Gisbourne in this undertaking, and he was successful in forming a company to supply the necessary money. Soon thirty or forty miles of the line inland from St. John's had been built, and the cable had been laid from New Brunswick to Prince Edward Island. The money then gave out, and the company refused to furnish more. The work had to be stopped.

In 1854 Gisbourne returned to New York to see if he could stir up any interest in his undertaking. He discussed his plan with Matthew Field, a New York engineer. Matthew Field was not interested in the undertaking himself, but he thought that his brother, Cyrus Field, might be. Cyrus Field, although only thirty-four years old, had already made a fortune and had retired from business. Cyrus Field was interested at once in the work which Gisbourne was trying to do. They had many long talks about the undertaking. After they had parted one evening, Field was tracing the path of the proposed telegraph line to St. John's, and the path of the steamers from there to Europe. Suddenly the thought occurred to him, "If it is possible to connect Newfoundland to the United States by cable, why not connect Newfoundland to Ireland?"

Before he dared hope that such a scheme could be carried out, he had to find the answers to two questions: Could a current of electricity be sent through a cable nearly two thousand miles long? Were there so many mountains and abysses at the bottom of the ocean that it would be impossible to lay a cable?

Morse assured him that a current could be sent through a cable of that length, and encouraged him to undertake the laying of it. Lieutenant Maury, who had just finished a survey of the bed of the Atlantic Ocean between Newfoundland and Ireland, reported that there were no mountains on the floor of the sea to interfere with the laying of the cable. In fact, Maury had found the great plateau on the floor of the ocean there which serves as a sort of submarine pathway between the two continents.

Thus encouraged, Field asked some of his friends to join him in this undertaking. Among these friends was his next-door neighbor, Peter Cooper. A company was formed, and was given permission to lay the cable. At this time the longest cable in the world was the one which reached from England to Holland. Not only was this cable short in comparison with the one Field proposed to lay, but it was laid in comparatively shallow water.

The first task was to complete the line to St. John's which Gisbourne had started. The company thought that this could be done in a few months. It took two years and a half. It was no easy matter to build a line across the forests and swamps and mountains and rivers and gulfs between St. John's and New Brunswick. The cable across the Gulf was very heavy (it weighed four hundred tons, although it was only eighty-five miles long), and it broke when the first attempt was made to lay it. At last, however, the line to St. John's was completed, and messages could be sent from there to many parts of the United States.

Field was then ready to tackle the much more difficult problem of laying a cable across the Atlantic. The first link in connecting Europe with America had cost about a million dollars. Field thought that it would be a good plan to ask the English to help with the laying of the cable across the Atlantic, because of course it would be very much more expensive than the line to St. John's.

While he was in London to ask for help with the laying of the cable, he went to discuss the cable with the famous electrician, Michael Faraday. Faraday was very much interested. He assured Field that the scheme was a workable one. When Field asked him how long it would take a current of electricity to cross the Atlantic through such a cable, Faraday answered, "Possibly one second."

Morse went with Field to ask the British Government for help in laying the cable. The Foreign Secretary, with whom Field discussed the matter, asked Field what he would do in case the cable broke and was lost at the bottom of the sea. "I would go to work to lay another," Field answered.

The British Government at length agreed to furnish a vessel to help lay the cable, and to take any soundings that were necessary. Field then succeeded in raising enough money to start the project.

Orders were given for the cable. It was to be ready to be laid on June 1, 1857. When Field returned to this country, he asked our Government to help him as the British Government had promised to do. After a hot contest over the passing of the bill, the Government finally agreed to do what Field asked, and the frigate Niagara, the largest and finest ship of our navy, was ordered to England to help in the laying of the cable. Early in July, 1857, half the cable was put aboard the Niagara, and the other half was put aboard the Agamemnon, an English ship.

The Niagara was to lay the cable from Valentia Bay on the coast of Ireland to mid-ocean. There it was to meet the Agamemnon. The two halves of the cable were to be spliced together, and the Agamemnon was to lay the cable from mid-ocean to Newfoundland. The Niagara had laid three hundred miles of the cable when the cable broke. The flags of the ships were put at half mast and the ships returned to Ireland. The company decided to postpone work for a year.

In 1858 it was decided that the Niagara and the Agamemnon, which had again been offered by the two governments, should proceed to mid-ocean, splice the cable, and then start in opposite directions, one toward Newfoundland and the other toward Ireland. They started to lay the cable in mid-ocean according to the agreement. Three miles only were laid when the cable broke. They met again, a new splice was made, and the ships again parted. Forty miles were laid. The cable broke. Again the cable was spliced together and the ships parted. Two hundred miles were laid when the cable broke once more. Both ships went back to Ireland.

The directors of the company met in London. As you can imagine, it was not a cheerful meeting. Some members of the company thought that another attempt would be utter folly. Some, however, still had faith in the scheme, and two weeks later the ships again left Ireland with a new cable.

This time the cable was laid without a single break. The Niagara reached Trinity Bay, Newfoundland, on the same day that the Agamemnon reached Valentia Bay. There was wild enthusiasm when it was learned that a cable had been successfully laid. Field sent the following message to President Buchanan, "The Atlantic cable on board the U.S.S.F. Niagara, and H.M. steamer, Agamemnon, was joined in mid-ocean Thursday, July 28, and has been successfully laid. As soon as the two ends are connected with the land lines, Queen Victoria will send a message to you, and the cable will be kept free until after your reply has been transmitted."

In many places celebrations were held in honor of the laying of the cable. An editorial in the *New York Evening Post* said, "All other things which may happen throughout the world on this day will be trifles."

Interesting placards were put up in shop windows. Some of them were:

The old Cyrus and the new
One
Conquered the World for Himself
The other
The Ocean for the World

---

July 4, 1776
August 16, 1858
Are the days we celebrate

---

Married, August, 1858
by
Cyrus W. Field
Old Ireland & Miss Young America
May their honeymoon last forever

---

Lightning
caught and tamed by
FRANKLIN
taught to read and write and go on errands by
MORSE
started in foreign trade by
FIELD, COOPER & CO
with
JOHNNY BULL
and
BROTHER JONATHAN
as
special partners

---

Between the 16th of August, the day on which Queen Victoria sent the first message to President Buchanan, and the 1st of September, ninety-seven messages were sent from Ireland to Newfoundland and two hundred and sixty-nine from Newfoundland. The first and second days of September had been chosen as the days for a general celebration of the laying of the cable. In the midst of the celebration on September 1, the cable ceased to work. A message congratulating Field for having succeeded in laying the cable was the last message sent over this cable of 1858. For days it was hoped that the fault in the cable was only a temporary one, but all efforts to put it into working order once more failed.

The next spring the company decided to raise another three million dollars for a new cable. Money was subscribed very slowly. The British Government refused to help. The directors of the company became discouraged. A financial panic swept over the country, and Field's business failed. In a few months after the failure, however, Field was once more at work on the problem of the cable. Constant improvements in the construction of cables were being made, and two new short cables had been successfully laid. Field was just as sure that a cable across the Atlantic was possible as he had been at the beginning.

By that time it was possible to telegraph from Valentia in Ireland to all the capitals of Europe, to Algiers in Africa, to Constantinople, and even to Omsk in Siberia. All that was required to put America in touch with all these places was the Atlantic cable.

Then came the Civil War. An Atlantic cable was needed more than ever before. Field spent much of his time working for the Government, but in his spare time he tried to get subscriptions to help with the laying of the cable. He told afterwards that he knew that many of his friends at this time tried to avoid meeting him for fear he would discuss the cable.

It was several years before the necessary money was raised. On July 22, 1865, the Great Eastern, the only ship afloat which could carry the new cable, which weighed seven thousand tons, set sail from Valentia. After more than a thousand miles had been laid the cable parted. The Great Eastern spent days in grappling for it. Three times the cable was caught and lifted for three quarters of a mile from the bed of the ocean, only to break and plunge once more into the sea. Finally no more wire and rope for grappling were left, and the ship returned to Ireland.

Still not discouraged by this failure, Field organized a new company the next year. The company was formed on the first day of March, 1866. Within fourteen days the entire three million dollars was subscribed. Within five months the cable had been manufactured, the Great Eastern had laid it successfully, and messages were being sent from one continent to the other.

People, remembering the cable of 1858, feared that this cable would work for only a short time. Fortunately, however, the Great Eastern, on her way back to England, succeeded in recovering the cable which had been lost the year before. A piece of new cable was spliced to the old cable and the cable was laid safely to the shores of Newfoundland. Soon, therefore, two cables were in operation across the Atlantic. On August 26, 1866, the cable was thrown open for public use. Since that time the telegraphic communication between Europe and America has not been interrupted. In time these two cables wore out, but by that time others had been laid.

Field deserves full credit for the laying of the cable. He was not a scientist. He was not the inventor of the instruments which are used in sending messages by cable. He was probably not the first person who thought of building a telegraph line across the Atlantic. But it was he who made up his mind that the cable could be laid and who, in spite of defeat after defeat, did it in the end. Probably few people would have succeeded in the face of the difficulties he met.

## XXXII. THE TELEPHONE

About forty years after the telegraph was invented, there was invented a more remarkable device for using electricity as a messenger — the telephone. To send or receive messages by means of the telegraph a person had to know the code. Even if he knew the code, he could not send or receive messages satisfactorily until after he had practiced for some time. Consequently few people had telegraph sets of their own. Telegraph messages were sent through stations at which there were trained operators. Telegrams are still sent in this way. In contrast, almost any one can use a telephone, for no code has to be used; you merely talk into a telephone, and the words you say are repeated. The telephone repeats what is said into it so accurately that you can often recognize the voice of the person who is speaking. You may even be able to tell if he has a cold and is hoarse.

Notice that the word "repeat" is used in the last paragraph. Perhaps you are surprised to be told that your voice is not "carried" to the person at the other end of the wire; but it is true. A man in San Francisco who is talking over the telephone to his friend in Chicago does not really hear his friend's voice; he merely hears an excellent imitation of it. No sound travels along the wire. Nothing travels along the wire but a current of electricity.

Perhaps you have ridden along a country road and have heard a humming noise which seemed to come from telephone wires on poles along the road. You may have heard some one say, "People are talking over the line; you can hear the hum of their voices." Such a humming is really made by the wind blowing across the wires. You could not tell even by putting your ear very close to a telephone wire when a message was being sent along that wire, for you cannot hear electricity traveling along a wire. The electric current travels noiselessly for a mile or a hundred miles or a thousand miles and at the end of the journey it repeats the message it was given to carry.

Suppose for a moment that a man in Chicago who wishes to talk to a friend in San Francisco has a voice so powerful that he can simply shout his message and make his friend hear him. Sound waves travel through the air at the rate of about eleven hundred feet a second. It would take them about three hours to travel from Chicago to San Francisco. The friend in San Francisco would hear a message, therefore, about three hours after the man in Chicago had shouted it. An electric current travels along telephone wires almost a million times faster than sound waves travel through the air. Over the telephone the man in San Francisco hears the sound less than a second after the man in Chicago has spoken. From the standpoint of time, it is fortunate, when the two telephones are far apart, that it is an electric current which travels from telephone to telephone, and not sound waves as many people seem to think.

How is it possible for an electric current to reproduce a spoken message? There are, as you surely know, two principal parts of the telephone instrument, the receiver and the transmitter. Figure 100 shows a section through each of these devices. Although these devices look very complicated, there are really only two important working parts in each one. The transmitter contains a thin sheet of alu-

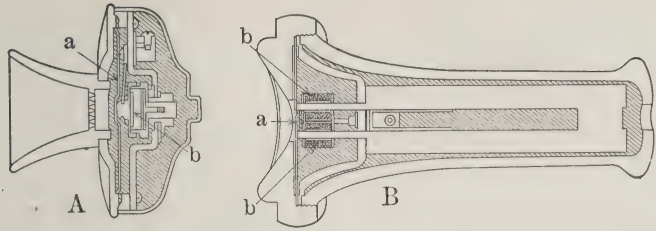


FIG. 100. *A*, TELEPHONE TRANSMITTER *B*, TELEPHONE RECEIVER

*a*, diaphragm —
*b*, carbon box

*a*, diaphragm —
*b*, magnet

minum called the diaphragm, and a small brass box filled with carbon. In the receiver there is a soft iron diaphragm, and there are magnets. The other parts of the transmitter and the receiver are merely to hold these parts in place, to protect them, and to provide for the proper connections.

The receiver of the telephone is very much like the sounder of a telegraph set although it doesn't look much like one. It contains an electromagnet which corresponds to the electromagnet of the sounder, and its soft iron diaphragm corresponds to the iron armature of the telegraph sounder. Indeed, if you connected the receiver to a telegraph key instead of to a transmitter, you could hear the dots and dashes just as you can with a sounder. The magnet in a receiver differs somewhat from that in a sounder because it is a combination of a permanent magnet and an electromagnet. The permanent magnet helps hold the diaphragm in position, and assists in obtaining loudness and clearness.

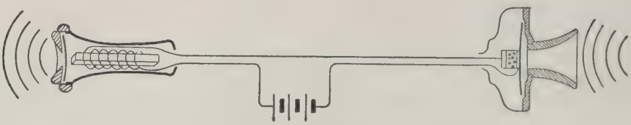


FIG. 101. A SIMPLE TELEPHONE CIRCUIT

The transmitter is somewhat like a key. Instead, however, of being a device for making and breaking the circuit, it is a device for making the current first weaker, then stronger.

Figure 101 shows a very simple telephone circuit. Before you can understand how a message spoken into the transmitter in this circuit can be repeated in the receiver, you must understand something about sound.

All sound is produced by motion. When a bow is drawn across a violin string, the violin string moves back and forth very rapidly. Waves of air move in all directions from the vibrating violin string. In case some of these sound waves enter your ear, they strike a thin membrane which we call the ear drum. The sound waves make this ear drum vibrate, and the nerves of the ear carry the message to the brain.

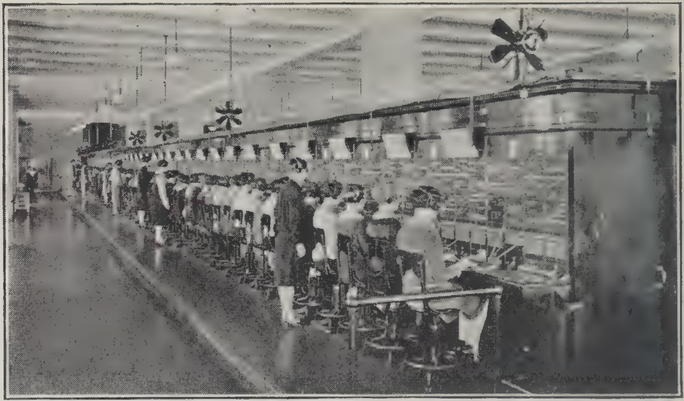
When you talk into a telephone, the waves of air strike the thin aluminum diaphragm and make it vibrate. By means of the current of electricity, the diaphragm in the receiver is made to vibrate in exactly the same way in which the diaphragm of the transmitter vibrates. The vibrating diaphragm of the receiver sets up sound waves in the air. These waves of air strike the ear drum of the person to whom you are talking, and he hears. The sound waves which come from the receiver are not, of course, the ones which came from the mouth of the speaker, but they are so nearly like them that it is hard to believe that they are not the same ones.

The basic principle of the telephone, then, is that the diaphragm in the receiver is made to vibrate just as the diaphragm in the transmitter vibrates. Tracing the path of the current in Figure 101 will help you understand how this is done. Notice that the current has to flow through the carbon box. This box is filled with fine particles of carbon, really bits of roasted coal. The back of the box is fastened so that it cannot be moved, but the front of the box can be moved in and out. Carbon is a fairly good conductor of electricity. How easily a current can flow through powdered carbon, however, depends upon how tightly the carbon particles are packed together. When the front of the box is pushed in, the carbon particles are pushed more closely together, and the current can pass through more easily. The current is stronger. When the front of the box moves outward, the carbon particles fall farther apart, and the current is weaker.

The electromagnet of the receiver is, you notice, in the circuit with the carbon box. You have already been told that the strength of an electromagnet varies with the strength of the current. You should now be able to understand how the message to be carried can be transmitted from the speaker to the listener. The diaphragm in the transmitter is fastened to the front of the carbon box. When the diaphragm of the transmitter moves in, the carbon particles are pushed closer together, the current is stronger, the electromagnet is therefore stronger, and the diaphragm of the receiver is pulled in farther. When the diaphragm of the transmitter moves out, the carbon particles move apart somewhat, the current is weaker, the electromagnet is weaker, and the diaphragm of the receiver moves out. Thus every movement of the diaphragm of the transmitter made by speaking near it is repeated by the diaphragm of the receiver. In this way the changing strength of the current causes the message spoken into the transmitter to be reproduced.

The diagram in Figure 101 shows the simplest possible connection of a receiver and a transmitter. In reality such simple circuits are seldom used. The telephone system of a city is an immensely complicated affair. Not only must there be a transmitter and a receiver for each telephone, but there must be devices for signaling the operator, bells as signals to bring some one to the telephone which is being called, and devices for registering coins put in coin-box telephones. In order that the electric current may carry the message successfully for several miles, induction coils or transformers are used in the circuits. In long distance telephone lines there are much more complicated devices for enabling the current to travel for hundreds or even thousands of miles with its message. In the chapter about radio you will be told about vacuum tubes, which are very important in long distance telephone circuits as well as in radio sending and receiving sets. Of course, in every telephone system there must be a central office where the wires leading to your telephone may be connected to the wires leading to the telephone to which you wish to speak.

Figure 102 shows a manual telephone central office. As you see, there are switchboards with many operators in such a large telephone central office. Each switchboard has many small holes in it called "jacks." Each jack is the doorway to a telephone line. Beside each hole there is a number, the number of the telephone to which that doorway leads. Notice the shelf between the operator and the upright part of the switchboard. On this shelf there are many switches and buttons, some of which are called listening keys. Many pairs of brass-tipped wires come up through this shelf, too. The brass tips at the ends of these wires are called "plugs."



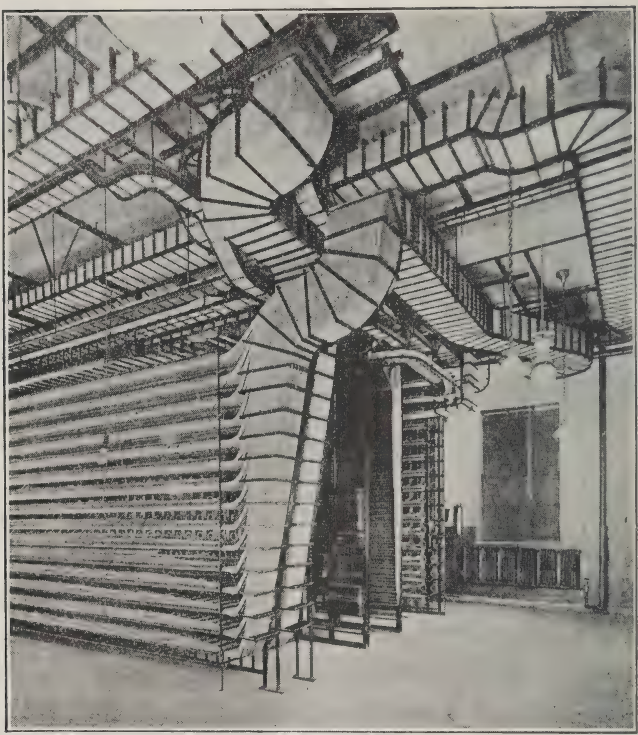
*By courtesy of American Telephone and Telegraph Company*

FIG. 102. A TELEPHONE CENTRAL OFFICE

Let us see what happens at the central office when you call a certain number. We shall suppose you wish to call number 999. You lift your receiver from the hook. (In certain telephone systems you may have to turn a crank before lifting the receiver off the hook.) Instantly a little electric lamp flashes near the jack through which your telephone call goes. There are many jacks or doorways leading to your telephone. In fact, at your central office, there is one within the reach of every operator. But there is only one doorway through which you can call other people. When the light near this jack flashes, the operator picks up a plug and pushes it into the jack. The lamp then goes out, but a lamp on the shelf near the cord of the plug she is using is lighted. She then presses a listening key which connects her head-phones with your telephone, and says, "Number, please." You give her the number. She picks up another plug whose cord is connected below the shelf with the cord of the first plug she used, and puts it in the jack numbered 999. Unless the central office is so equipped that the ringing begins automatically, she then presses a key which rings the bell of 999. As soon as some one lifts off the receiver of 999, the light on the shelf near the cord goes out. This shows the operator that the call is answered. When the receivers are hung upon the hooks again, two lamps on the shelf near the cord are lighted, and the operator takes out the plugs and breaks the connection.

In a large city system there are so many telephones that there must be many central offices. When you call a number, you must also name a central office. If your number is Dorchester 5114 and you wish to telephone to Fairfax 5186, the Dorchester central office must be connected to the Fairfax central office to enable you to get your number. Putting a call through is, in that case, more complicated than when both telephones are connected to one central office. Figure 103 gives you an idea of the number of wires needed in one city central office to give the subscribers satisfactory telephone service.

Recently automatic devices have been put to use



*By courtesy of American Telephone and Telegraph Company*

FIG. 103. CABLES AT A CENTRAL OFFICE

in some places to take the place of operators. These machines connect your telephone with the number to which you wish to speak.

If a record could be kept of all the messages which go through any one switchboard in the course of a day, what a story it would tell of the present importance of the telephone in our life in America. Perhaps one message would be a call for a doctor, another an order for groceries, a third a call for a taxi, a fourth an inquiry about the time of a train, a fifth a telegram to be sent, a sixth a conversation with a person who is shut in by illness, a seventh a fire alarm, and so on and on. There were large cities before there were telephones, but telephones play so large a part in our business and social life to-day that a modern city certainly couldn't be kept in smooth working order without them.

By means of your telephone you can now get in touch, not only with any one of millions of subscribers in the United States, but also with subscribers in Canada, Cuba, Mexico, Great Britain, and certain cities on the continent of Europe. In 1927 telephone service was first established between the principal cities of Mexico and all points in the United States. In 1927 it also became possible to telephone from any telephone in this country across the sea to any telephone in Great Britain. This was made possible when the American Telephone and Telegraph Company succeeded in using ordinary wire telephone lines and radio together in carrying a message. If you, in Chicago, wished to talk with a friend in London, wires would carry your message by long distance to a radio station. From there the message would be carried by radio to a radio station in Great Britain. The last part of the message's journey to your friend in London would be again by wire. Of course you would hear your friend talk just as if the message traveled by wire all the way. This trans-Atlantic service is being extended rapidly.

You were told in an earlier chapter that pictures can be telegraphed from one city to another. This sending of pictures by means of electricity is sometimes spoken of as telephotography. Telephone lines as well as telegraph lines can be used for telephotography. The American Telephone and Telegraph Company reports that its lines are being used in transmitting, among other things, news pictures, cartoons, X-ray pictures, photographs of finger prints, advertisements, messages in foreign languages, and important legal documents. The picture of anything which can be photographed can be transmitted by wire. You were told in an earlier chapter that an airplane can carry a paper with a written message to a distant destination more rapidly than any other messenger. In case the destination is a city where the necessary receiving apparatus is in operation, such a message can be photographed and the photograph can be reproduced by electricity in the distant city in a small fraction of the time it would take an airplane to carry the message.

At present there are over eighteen million telephones in the United States alone. We have more telephones than all the rest of the world put together. Over three hundred seventy-five thousand people in this country earn their livings by working in the telephone industry. In addition, more than fifty thousand are employed in the manufacture of telephone equipment. Over sixty million miles of wire are in use for connecting the telephones of this country; and more than seventy million calls a day is the average for the whole country. These figures give you some idea of what the telephone has come to mean in our modern life.

## XXXIII. THE STORY OF THE INVENTION OF THE TELEPHONE

At the great Centennial Exhibition held in Philadelphia in 1876, a young inventor had on display an electrical invention which he had recently patented. The young inventor was Alexander Graham Bell. He was already fairly well known as a teacher of the deaf. His exhibit at the exposition, however, attracted very little attention, for there were many other new electrical inventions on display.

One day the judges started on a tour of inspection to examine all of the electrical exhibits. Among the judges were Joseph Henry, who then knew more about electricity than any other man in America, and Sir William Thomson, an Englishman and one of the great scientists of that time. With the judges on this tour of inspection came also Dom Pedro, the Emperor of Brazil. Bell followed the judges as they moved from one exhibit to another. He was, of course, very eager for them to see his invention. Just before they reached the place where his invention was on display, they decided to look at no more inventions that day. Bell was greatly disappointed. He had planned to leave Philadelphia the next morning.

Just as the judges were leaving, Dom Pedro caught sight of Bell. Dom Pedro had met him in Boston and had been much interested in his work with deaf people there. Dom Pedro spoke to Bell at once and asked him about his work with the deaf. Bell answered his questions, and then told him of his invention. Dom Pedro very courteously asked Bell to show him the invention, and the judges followed them to Bell's exhibit. Bell asked the Emperor to hold to his ear a queer-looking instrument to which two wires were attached. Dom Pedro did not know what to expect. Then Bell went to the other end of the wires, and spoke into another small instrument. When Dom Pedro heard words coming from the instrument at his ear, he cried out in surprise, "It talks."

Every one in the group then wished to hear the instrument talk. Sir William Thomson said that this was the most wonderful thing he had seen in

America. The telephone — for this invention was, of course, the telephone — became one of the much-talked-of exhibits at the exposition.

Six years before this time Bell had come with his father from Scotland to Canada. Bell's family for a long time had been interested in voice training. His father was particularly interested in teaching people to overcome speech defects such as stammering, stuttering, and lisping. It was not surprising that Bell also should be interested in these things, and should decide to follow his father's profession. His father had worked out a system of symbols which showed the positions and use of various vocal organs in producing the different sounds of speech. Bell used this system of "Visible Speech" in London at a school for deaf children in teaching the deaf to speak.

Later, after he came to America, Bell was offered a position as a teacher of the deaf in a new school in Boston. He accepted. He was so successful that he was made a professor in Boston University so that he could teach his method to teachers. He also opened a private school of his own. In 1873 he was engaged to teach a little deaf boy, George Sanders. In the fall of that year he moved to Salem, Massachusetts, and lived, with the child, in the home of the little boy's grandmother.

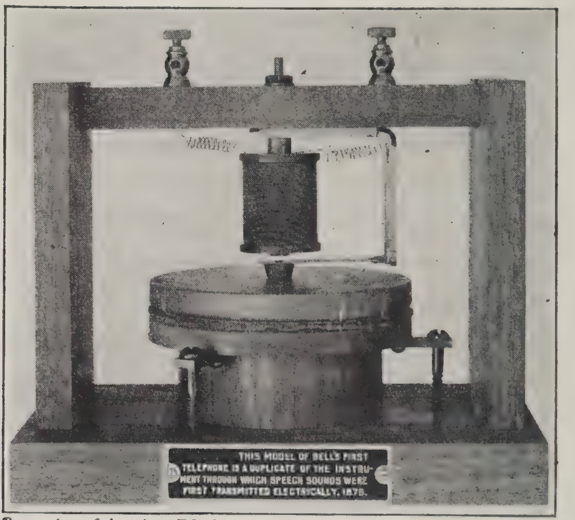
Before he left England Bell had begun to experiment with telegraphy. He hoped to invent an apparatus which would send several messages at one time over a single wire. Busy and interested as he was in his work with the deaf people in Boston, he had found some time for his experiments with telegraphy. When he moved to Salem, he was allowed to have a work-bench in the cellar of the Sanders home. Before long Mr. Sanders became so much interested in Bell's work with the telegraph that he offered to pay the cost of the experiments.

Before he came to America, Bell had also had the idea of talking over a telegraph wire. He could see that a talking telegraph, or telephone, would be, in many ways, an improvement over sending messages in dots and dashes. While he was working on his telegraph invention, he was trying also to work out a plan for a telephone. Perhaps his study of the vocal cords and of the ear helped him somewhat in planning the telephone. In fact he said at one time, years later, that if he had known more about electricity and less about sound he probably never would have invented the telephone.

Mr. Sanders, and Mr. Hubbard, who had also become interested in Bell's experiments, urged him to finish the telegraph invention first because they were sure that it would be more profitable than the telephone. He spent most of his time, therefore, on the telegraph, although he thought the idea of the telephone more important.

At about this time he went to consult Professor Joseph Henry about his telegraph. While he was there he told Professor Henry of his idea for a telephone. Professor Henry encouraged him to work upon the problem. When Bell said that he feared that he did not have enough knowledge of electricity to succeed in making a telephone, Henry's answer was simply, "Get it."

In 1874 Bell began having his instruments made in a shop in Boston where a young man named Thomas A. Watson was employed. Watson helped Bell with his experiments. Mr. Sanders was still supplying money for the experiments, and Bell and Watson worked hard on the telegraph. One day they were tuning up the telegraph instruments to go on with the experiments. The contact point on one of the armatures was screwed down too far. When Watson gave it a little pull, a faint sound was heard from the instrument at the other end of the line. Bell heard this faint sound and at once understood what it meant. A telephone was a possibility! Probably no other man living at that time would have understood the importance of this sound when he heard it. Bell knew at once that he had learned the last thing he needed to know to invent the telephone. This was on June 2, 1875. Bell gave directions to Watson that evening for the making of the first telephone. When it was tested the next even-


THIS MODEL OF BELL'S FIRST
TELEPHONE IS A DUPLICATE OF THE INSTRU-
MENT THROUGH WHICH SPEECH SOUNDS WERE
FIRST TRANSMITTED ELECTRICALLY, 1875.

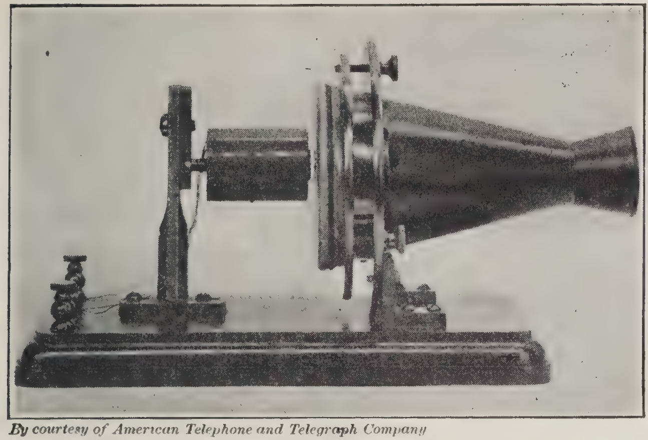
*By courtesy of American Telephone and Telegraph Company*

Fig. 104. Model of Bell's First Telephone

"This model of Bell's first telephone is a duplicate of the instrument through which speech sounds were first transmitted electrically, 1875."

ing, Watson was able to recognize Bell's voice and almost understand the words. Figure 104 shows you how this first telephone looked. Notice the diaphragm and the electromagnet.

Then followed experiments to improve the telephone so that it would transmit speech clearly, and thus become a practical device for use in talking at a distance. Diaphragms of many sizes made of many kinds of materials were tested. Electromagnets of a multitude of sizes and shapes, and permanent magnets of different sizes and shapes were tested,



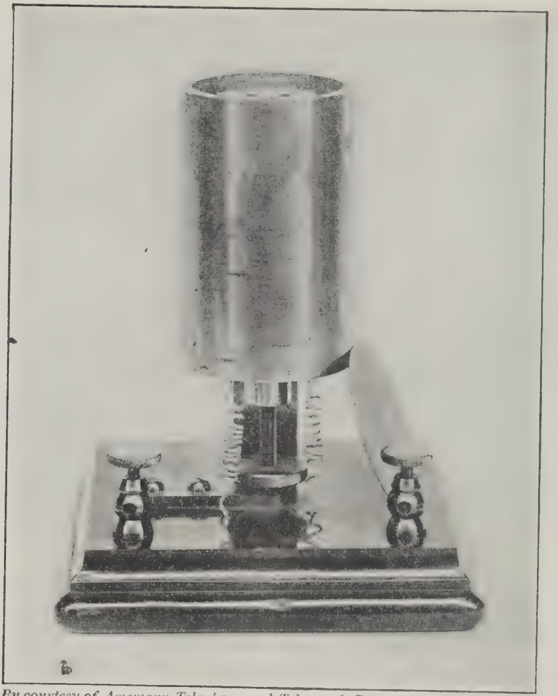
*By courtesy of American Telephone and Telegraph Company*

FIG. 105. THE CENTENNIAL TRANSMITTER

too. Various designs for mouthpieces were experimented with.

One evening about ten months after the invention of the telephone, Bell and Watson got ready to test a new form of the instrument. Bell called into the instrument, "Mr. Watson, come here; I want you." Watson, who was in another room listening eagerly at the other end of the line, put down his instrument quickly and hurried in shouting, "I hear you; I can hear the words." Thus "Mr. Watson, come here; I want you" was the first complete sentence ever heard clearly over a telephone.

The following June the telephone was displayed at the Centennial Exhibition. Figures 105 and 106 show the transmitter and the receiver of the telephone displayed there. Although these two in-



*By courtesy of American Telephone and Telegraph Company*

FIG. 106. THE CENTENNIAL RECEIVER

struments did not look very much alike, they were really very much alike. They were both very much like the receivers we now use; each contained an electromagnet and a thin iron diaphragm. When the diaphragm of the transmitter was made to vibrate, by speaking near it, the current flowing through the magnets caused the diaphragm in the receiver to vibrate in exactly the same way. Thus a message could be reproduced.

Although Joseph Henry and Sir William Thomson were very enthusiastic about the telephone, it was difficult to convince most people that it was anything more than an interesting scientific toy. Bell began giving lectures and demonstrations to explain it and to show how it could be used. One of the first of these lectures was at Salem. A telephone instrument in the Boston laboratory was connected with a telephone instrument in the Salem lecture hall. Watson remained in the Boston laboratory. Bell would speak into the telephone at Salem and tell Watson to sing a certain song. He would then place the telephone so that the audience could hear the song. Then he would ask Watson to have some musical instrument played, and the crowd could hear the music even though it was being played in Boston. Of course, to us who are used to radio concerts this doesn't seem remarkable, but it probably seemed as wonderful to people then as hearing a London concert by radio seems to us now. At the close of the lecture the people in the audience were allowed to test the telephone for themselves.

These lectures soon became popular. Bell gave them in a number of places. People thought of the telephone as a device for providing a pleasant kind of entertainment, just as most people think of radio now.

Soon, however, people began to realize that the telephone could be used to good advantage in getting important messages quickly from one place to another. Orders for telephones began to pour in by the hundreds and then by the thousands. The Bell Telephone Company was formed. Telephone exchanges were established in all the large cities of this country. Subscribers were given one instrument each, which served as both a transmitter and a receiver. If you wished to talk to the person at the other end of the line, you spoke into the mouthpiece. If you wished to listen to what the person at the other end of the line was saying, you put your ear to the mouthpiece. Of course, people were not accustomed to using telephones, and, since the same instrument, at the very first, had to be used as both transmitter and receiver, such signs as the following were sometimes found: "Don't talk with your ear, nor listen with your mouth."

Since that time, as you know, remarkable improvements have been made in the telephone, and the telephone system has grown at a tremendous rate. Forty years after Bell made the first telephone, the telephone line between New York and San Francisco was opened. At the official opening, Bell in New York spoke over the line to Watson in San Francisco. He used a model of his first telephone. The words he spoke were, "Mr. Watson, come here; I want you."

When we think of the millions of telephones in use to-day, and of the hundreds of millions of dollars spent each year for telephone privileges, we can readily understand why the patent which was given to Bell the year of the Centennial Exhibition has been called the most valuable patent ever issued in any country.

## XXXIV. RADIO

When Lindbergh arrived safely in France at the end of the first non-stop New York to Paris flight, the newspapers here printed this news in big headlines. To many thousands of people who read these headlines, however, this news was no news at all; they had already heard it by radio.

Radio receiving sets are now very common; probably you have one of your own. There are nearly six million of them in the United States alone. This means that a large percentage of the people of the country can now be reached by radio. Radio made it possible, for example, for more than two million persons to hear President Coolidge deliver his inaugural address on March 4, 1925.

Only a few years ago most of the receiving sets were homemade sets. They were mere playthings. Radio has far outgrown that stage. Manufacturing radio sets is now one of the country's important industries.

Does radio seem to you the most remarkable of all the ways of sending messages by electricity? It does to most people. It seems almost like a miracle to get a message from one place to another by means of electricity without using wires to carry a current from one station to the other. Some people think of wireless as one thing and of radio as another. What these people have in mind as "wireless" is the wireless telegraph. By "radio" they mean the wireless telephone. In one the message is sent in dots and dashes; in the other any sound produced in front of the transmitter is reproduced in the receiver. The word "radio" really includes both the wireless telegraph and the wireless telephone. Radio is a better name than wireless because neither the wireless telephone nor the wireless telegraph is really without wires. There are the wires of the antennæ, and there are wires used in the construction of the sending and receiving instruments. There are no wires, however, to connect the sending station with the receiving station.

Perhaps we should not think of radio as being any more remarkable than sending messages along wires. Light, which, as you have been told, was the most effective messenger before electricity was used in sending messages, traveled from station to station without wires. It couldn't be made to travel through wires. Perhaps the thing we should marvel at is that an electric current can be made to travel through wires and carry the message to the station for which it is intended.

Whether or not radio is the most remarkable, it is certainly the newest way of sending messages by means of electricity. In 1896, only a little more than thirty years ago, Marconi obtained his first wireless patent in England. Three years later he was able to send messages across the English Channel, a distance of thirty-two miles. In 1901 for the first time a message was sent by radio across the Atlantic. It wasn't a real message. It was merely the letter *s* repeated twenty times. This signal was sent in Morse Code from Poldhu in Great Britain to St. John's in Newfoundland, a distance of eighteen hundred miles. Although radio progressed in leaps and bounds after that, it was not until 1915 that a spoken message was carried across the Atlantic by radio. In this same year, Mr. Vail of the American Telephone and Telegraph Company talked by radio from New York to a friend in San Francisco, three thousand miles away. In November, 1920, a Pittsburgh station broadcast the results of the presidential election; no real broadcasting had been done until that time. And not until 1927 was regular radio-telephone service established between London and cities in this country.

Figure 107 shows one of the early steps in the

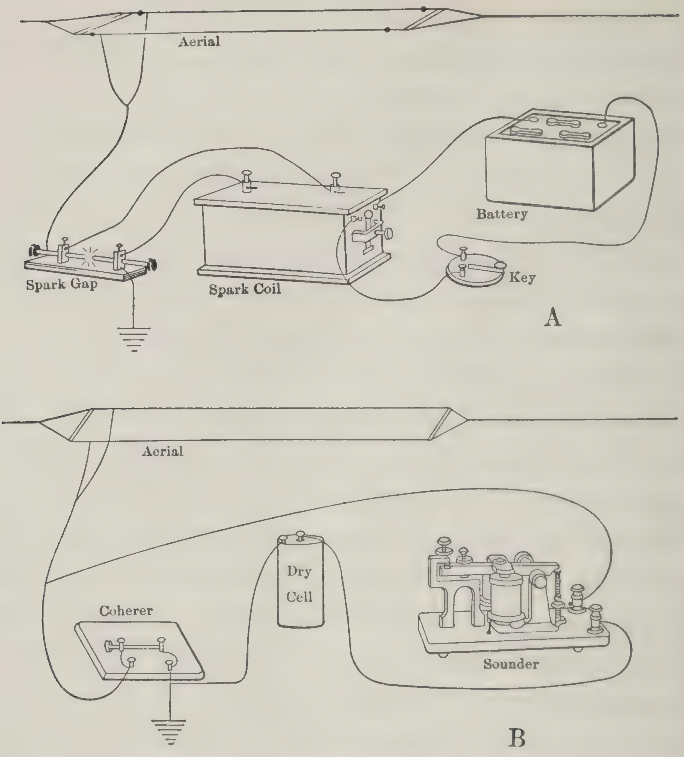


FIG. 107. SIMPLE RADIO SETS
*A*, sending set — *B*, receiving set

development of radio sets. These sending and receiving sets are similar to the ones which Marconi used in his first sending and receiving stations. Probably you wouldn't recognize them as radio sets if you saw them.

The sets shown in Figure 107 are much simpler than those we use to-day. Perhaps learning about them will help you understand those we use now. Notice that the sending set includes a key, a spark coil, and a spark gap. Notice, too, that a wire is connected from one side of the spark gap to the antenna, and that another reaches from the other side of the spark gap to the ground. A spark coil or induction coil is much like a step-up transformer. When the key is pressed down, a current flows through the primary coil. An interrupter on the spark coil makes and breaks the circuit just as the spring attached to the armature does in an electric bell. Whenever the circuit is made or broken in the primary coil, a current flows through the secondary coil, the ends of which are connected to the two sides of the spark gap. The voltage in this circuit is so great that a spark jumps across the spark gap. This spark causes electric waves to move out in all directions from the aërial. There is no spark unless the key is pressed down. Therefore no electric waves move out from the sending station unless the key is pressed down.

At the receiving station you notice that the coherer is in the circuit with a cell and a telegraph sounder. Notice, too, that one end of the coherer is connected to the aërial, the other to the ground. It looks from the drawing as if the armature of the sounder would be held down all the time, because at first glance there seems to be a complete circuit.

However, there is not as a rule a complete circuit because of the resistance offered by the coherer. This coherer consists of a small glass tube filled with nickel and silver filings. Both nickel and silver are good conductors, but these filings touch each other so lightly that there is so much resistance that the current cannot operate the sounder. When, however, the key at the sending station is pressed down, the electric waves cause the filings in the coherer to rearrange themselves in such a way that the current from the cell flows through the coherer and pulls down the armature of the sounder. The current continues to flow as long as the key at the sending station is held down. As soon as the key at the sending station is released, the electric waves no longer affect the coherer. The filings are then jarred apart by a little clapper not shown in the diagram. They remain apart until the spark coil once more sends out waves of electrical energy. Since the current flows through the coherer and pulls the armature down whenever the key at the sending station is held down, it is possible to send and receive messages in dots and dashes with such sets as these.

Marconi was not the first scientist to find out that electric waves move out in all directions from the spark produced by a spark coil. Maxwell, an English scientist, had figured that there must be such waves, and Hertz, a German scientist, had done many experiments with these electric waves. However, many scientists had worked with spark coils without discovering these electric waves. This is not surprising. It is not difficult to tell that such a spark sends out light waves. If it were not for them, the spark could not be seen. It is not difficult to tell that sound waves move out from a spark. If it were not for them, no sound could be heard when the spark jumps across the gap. But our eyes can't detect electric waves as they do light waves; our ears can't detect electric waves as they do sound waves. We can't see or hear or smell or feel or taste these electric waves. No scientist could prove that a spark sends out electric waves until he had devised some sort of detector such as the coherer. Marconi did not invent the coherer. It was invented by Professor Branly of Paris. Marconi was the first person, however, who was able to use the coherer in a wireless set for receiving messages. It was he who found that a message could be sent much farther if the spark gap and coherer were connected to antennæ and to the ground. It was he who devised a way of jarring the filings apart after the key at the sending station was released. And it was he who first succeeded in sending messages for a considerable distance.

As soon as Marconi had showed that radio was a possibility, many scientists set to work to improve this first scheme. Of course, with Marconi's set messages could be sent only in dots and dashes. If wireless telegraphs are possible, wireless telephones are possible, too, argued many scientists. Many, therefore, began working on the problem of the wireless telephone while others worked on the telegraph.

Radio as we have it to-day can't be credited to any one or even to any two or three or ten scientists. Even the boys who were thrilled at the idea of getting messages "out of the air," and who built and experimented with receiving sets of their own, played a part in the development of radio.

Soon the coherer was discarded for other types of detectors. The crystal detector became popular. Figure 108 A shows the diagram of a very simple receiving set with a crystal detector. Notice that telephone receivers are used instead of a telegraph sounder in the circuit with the crystal detector. Whenever the key is pressed in the sending set, the electric waves which reach the receiving set cause a current to flow up and down in the wire connecting the aërial to the ground. Such an alternating current cannot operate the telephone receivers. The receivers are put in a branch circuit with the detector. The crystal used in most cases is a crystal of galena. Such a crystal allows the current to flow through it in only one direction. Therefore, in the

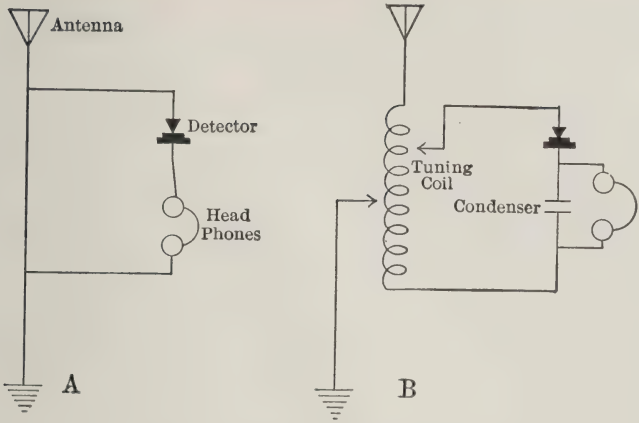


FIG. 108. CRYSTAL RECEIVING SETS

branch circuit the current flows in only one direction. This direct current can operate the telephone receivers, and a buzz is heard in these receivers. The diaphragms of the head-phones vibrate as long as the key of the sending station is held down. A long buzz means a dash, and a short buzz a dot.

Such receiving sets proved to be fairly satisfactory in cases where the sending station and the receiving station were only a few miles apart, and in case only one near-by station was sending messages at one time.

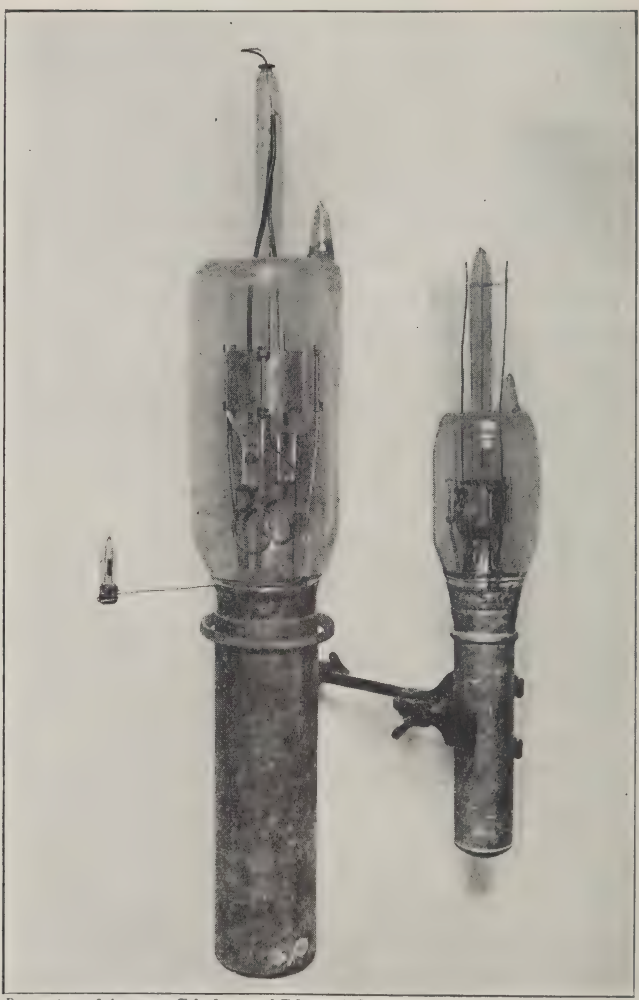
This type of crystal set was soon improved by adding a tuning coil and a condenser to it. Figure 108 B shows the diagram of a crystal set with these additions. With such a crystal set, stations many miles away could be heard.

As the number of stations increased, the difficulty of getting a message clearly became greater. When several messages were being sent at one time, the electric waves interfered with one another, and no messages came through clearly. This was remedied by adding tuning coils to the sending sets. By means of these tuning coils, the lengths of the electric waves could be changed. It was found that if one station sent out messages with waves of a certain length, and another station sent messages with waves of a different length, there was much less interference. Perhaps it is hard for you to think of an electric wave which you cannot see as having a definite length, but it has. Moreover, the length of the wave can be regulated.

The real public interest in radio began when wireless telephones were shown to be practicable; when it was found that sound waves coming from voices or from musical instruments could be made to modify electric waves in such a way that these electric waves could be made to reproduce the sound in the receiving set. In a telephone, you remember, the sound waves which strike the diaphragm vary the strength of the current in such a way that the diaphragm of the receiver is made to vibrate just as the diaphragm of the transmitter vibrates. In the wireless telephone the electric or radio waves are varied so that they can be made to reproduce the sound.

Of course, in both the wireless telegraph and the wireless telephone, only radio waves travel from station to station. A small boy once asked an aviator if he had ever been up high enough to hear all the messages going out from the radio stations. The aviator said that he had not. You should understand that, no matter how high he had flown, the aviator couldn't have heard any messages unless he had had a receiving set to make the radio waves produce sound waves. When the two million people heard President Coolidge's address, they didn't really hear his voice; the sound they heard was made right in their radio receiving sets.

One of the very important inventions which have made wireless telephones possible is the vacuum or audion tube. You have already been told that vacuum tubes are very important in long-distance telephone lines. The vacuum tube was invented by the American electrician, Lee DeForest. Other inventors improved it greatly. Vacuum tubes are now so common that you are almost sure to have seen one. They vary in size and shape, as Figure 109 shows. The "peanut" tube on the left can be operated with one dry cell; the one in the center is a one hundred kilowatt tube. Probably the vacuum tubes you have seen look more like electric lamp bulbs than those shown in the picture do. Although all vacuum tubes look more or less like electric lamp



*By courtesy of American Telephone and Telegraph Company*

FIG. 109. VACUUM TUBES

bulbs, they are not nearly so simple. Each one contains a tungsten filament, a grid which consists of fine wire wound on a glass frame, and a metal plate. As the name suggests, the air has been pumped out of the tube so that it contains an almost perfect vacuum.

Vacuum tubes are remarkably useful. They can be used as oscillators to produce continuous electric waves. They can be used as modulators which enable the sound waves to vary the strength of the electric waves. They can be used as detectors to supply a direct current when they are supplied with an alternating current. They can be used as amplifiers to magnify a weak current much as a relay does in a telegraph circuit. All these tasks they are called upon to perform in modern radio sets.

There are many plans for using vacuum tubes in receiving sets. In books and newspapers you probably have seen diagrams of "hook-ups" for vacuum tube sets. The symbols given in Figure 110 will help you understand such diagrams.

The simplest vacuum tube set is one in which there is only one vacuum tube, which serves as a detector. Figure 111 shows the hook-up for such a set. Let us see how a vacuum tube acts in a set of this kind. Notice that the filament of the tube is in a circuit with a rheostat and the A battery. The "plate" circuit includes the B battery and the head-phones.

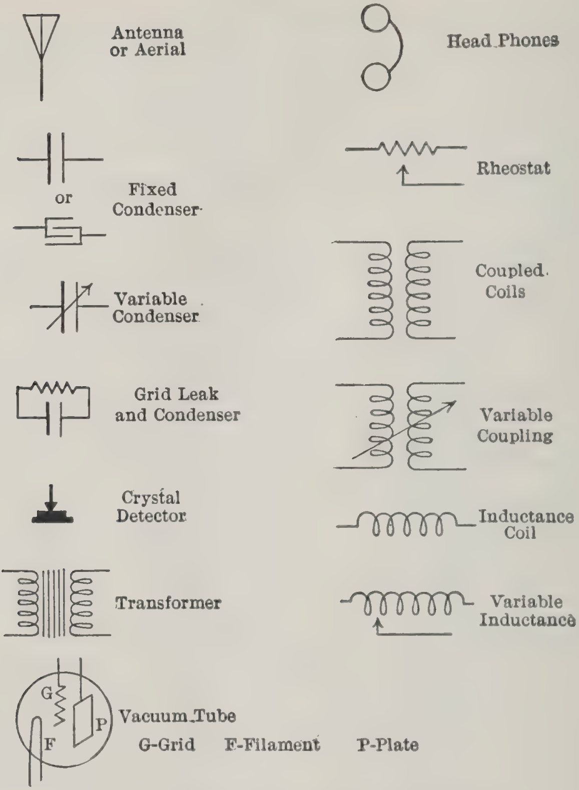


Fig. 110. Symbols Used in Radio Diagrams

If you try to trace the path of the current from the B battery, you will find that there is a break in the circuit at the tube. The current has no way of getting from the filament to the plate. No current flows through the head-phones. When the current from the A battery is sent through the filament, the tungsten filament is heated white hot just as it is in

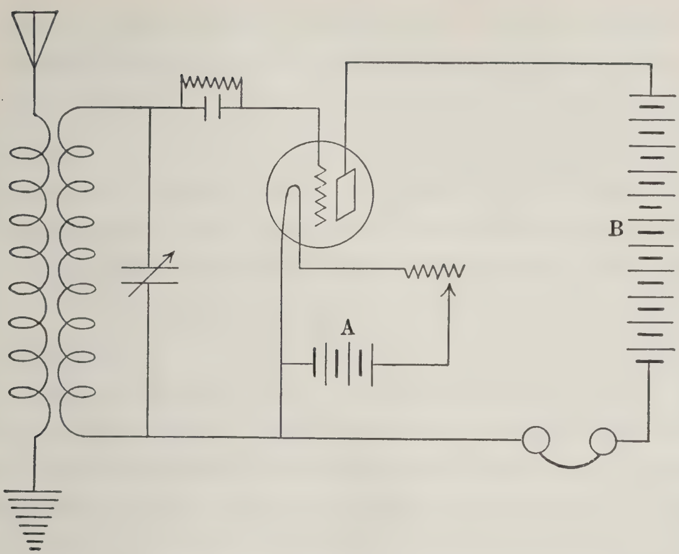


FIG. 111. DIAGRAM OF A SIMPLE VACUUM TUBE RECEIVING SET

an ordinary electric lamp bulb. This very high temperature forces out of their places in the filament millions of electrons, those tiny units of electricity about which you have been told. You may think of these electrons as forming a sort of cloud about the hot wire. If it weren't for the plate, the electrons would remain close to the wire. The plate, however, as you see from the diagram, is attached to the positive pole of the B battery. The positive plate pulls electrons from the filament across the gap in the circuit between the filament and the plate. A current then flows through the head-phones.

Head-phones are much like the ordinary telephone receivers. Of course, when a current flows steadily through a telephone receiver, the diaphragm of the receiver is pulled toward the magnet and held there. No sound is produced so long as there is no change in the current. To make a telephone diaphragm vibrate, the strength of the current must be changed. It is in varying the current which flows through the head-phones that the grid plays its part.

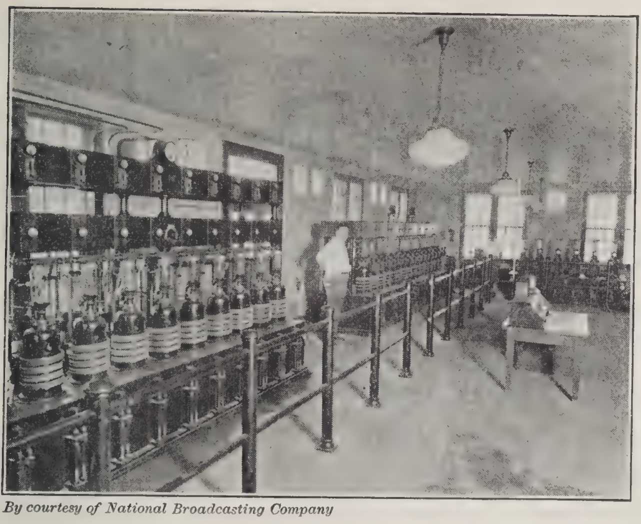
When radio waves of the length for which the set is tuned strike the antenna, electrons surge up and down between the antenna and the ground, and in and out of the grid. When the grid is positive, it helps pull electrons from the filament, and a stronger current flows through the head-phones. When electrons surge into the grid and make it negative, the negative charge pushes electrons back toward the filament, and few flow from the filament to the plate. The current flowing through the head-phones is lessened. In this way a negative grid tends to shut off the head-phone current, while a positive grid makes it stronger. Thus, by the use of the vacuum tube, the radio waves are made to change the strength of the current in such a way that the diaphragms in the head-phones vibrate and reproduce the sound made at the sending station.

In a set of this kind you see that the vacuum tube acts somewhat as the crystal does in a crystal set. A vacuum tube used in this way is sometimes spoken of as a vacuum valve since it allows a current to flow through the head-phones in one direction only.

If a loud-speaker were put in place of the head-phones in the circuit shown in Figure 111, the sound produced would be only a whisper if it could be heard at all. In the sets with which loud-speakers are used, other vacuum tubes are used as amplifiers. If the current flowing through the plate circuit in Figure 111 were used to vary the grid of another vacuum tube, instead of to make the diaphragms of the head-phones vibrate, a much stronger current could be made to flow through the plate circuit of the second tube. A series of tubes steps up the current until it is strong enough to make the diaphragm of a loud-speaker vibrate satisfactorily. Some sets have five or even more tubes used in this way as amplifiers. The "hook-ups" for such sets are complicated. Some sets have other tubes which make it possible to use the alternating current of the electric lighting circuit instead of the direct current of batteries. Isn't it interesting to think how much of the remarkable progress made by radio is due to the fact that heating a metal filament in a vacuum drives off electrons?

Crystal sets can be used for radio telephone receiving sets as well as for radio telegraph receiving sets. Crystal sets, however, are now seldom used; they have been pushed aside by the vacuum tube sets. Vacuum tube sets are better than crystal sets for three reasons. The range of vacuum tube sets is greater than that of crystal sets. With crystal receiving sets telephoning across the Atlantic, for example, would be impossible. Vacuum tube sets can be made to produce sound more loudly than crystal sets; loud-speakers can be used instead of headphones. In addition, vacuum tube sets tune better than do crystal sets; that is, it is easier to tune out stations which you do not wish to hear. Most radio broadcasting is now carried on at wave lengths ranging from two hundred to five hundred forty-five meters. A meter is a little longer than a yard. If one broadcasting station is broadcasting on a wave length of four hundred sixteen meters, and another on a wave length of four hundred twenty-two meters, it is more difficult to tune one station out and hear the other clearly, other things being equal, than if one station is broadcasting on a wave length of four hundred sixteen meters, and the second on a wave length of five hundred sixteen meters. Some vacuum tube sets have very high selectivity. This means that with these sets interference can be tuned out easily so that any one station can be heard clearly.

It is a far cry from the very simple crystal sets to the elaborate vacuum tube sets of to-day. Even the best vacuum tube sets of a few years ago with their



*By courtesy of National Broadcasting Company*

FIG. 112. TUBES USED AT A LARGE BROADCASTING STATION

long outside aërials, their head-phones, and their heavy storage batteries seem crude beside the newer sets with enclosed loop aërials, devices for using lamp-socket power, and powerful loud-speakers.

Although vacuum tube sets have become more and more complicated, they have also become easier to operate. The number of dials to be turned has gradually been reduced. Although using lamp-socket power has made the sets themselves less simple, it has lessened or done away altogether with the work of taking care of batteries.

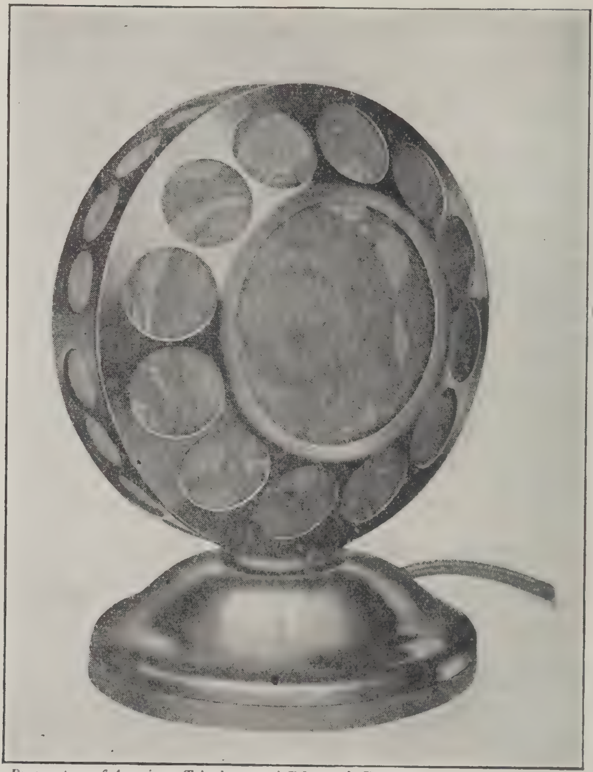
Vacuum tubes are not only important in receiving sets, but, as you must have guessed from reading, on page 293, the list of things vacuum tubes are able to do, they form a very important part of the equipment of radio telephone broadcasting stations. Figure 112 shows the high-power tubes with which one of the big broadcasting stations is equipped. Vacuum tubes which serve as oscillators in broadcasting sets cause electrons to surge back and forth in the antennæ. These electrons by their movement cause radio waves to move out in all directions from the antennæ. These waves move at the rate of about one hundred and eighty-six thousand miles a second, the same speed at which light travels. In conversations about radio you hear the word "frequency" used often. By frequency we mean the number of radio waves generated in a second of time. If a million waves move out from a broadcasting station in a second, the waves are shorter than if only five hundred thousand waves a second were generated. High frequencies, therefore, mean short waves, and low frequencies longer waves.

Each broadcasting station has a frequency assigned to it. When you see a list of radio stations in the newspapers, you will notice that a certain frequency is given after each station. In many cases the wave length is given, too. Each station is required to announce its frequency several times during a program. The station may tell its wave length or not as it chooses. Frequency is given in kilocycles. If the frequency of a station is five hundred and fifty kilocycles, five hundred and fifty thousand radio waves a second are projected into space from the aërial at that station, and the wave length is about five hundred and forty-five meters. If the frequency assigned to the station is seven hundred and forty kilocycles, seven hundred and forty thousand waves are generated per second, and the wave length is about four hundred and five meters.

Figure 113 shows a microphone, another important part of a radio telephone broadcasting set. It is somewhat like an ordinary telephone transmitter. The microphone must be so placed that the sound waves which are to be reproduced strike it. You probably have seen microphones in halls where lectures are being given or concerts are being played.

The vacuum tubes used as modulators in a broadcasting set enable the sound waves which strike the microphone to change the radio waves so that messages can be carried.

The vacuum tubes and the microphone do not make up the whole of a radio broadcasting set. In addition to the microphone and tubes, there must be a power plant to furnish a current of electricity, there must be devices for regulating the frequency, there must be transformers and condensers, and there must be an antenna and a ground connection. Figure 114 shows a portion of the control board at one of the big broadcasting stations. These operators are

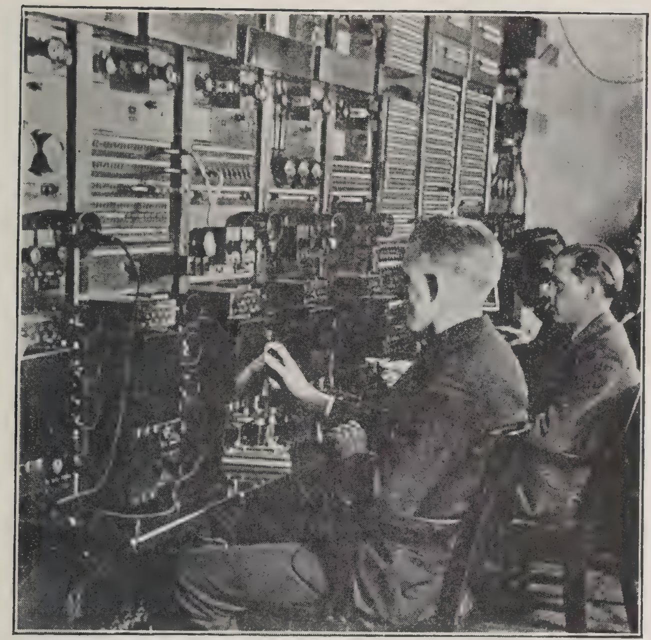


*By courtesy of American Telephone and Telegraph Company*

FIG. 113. A MICROPHONE

"monitoring" programs going to various stations in a chain of broadcasting stations.

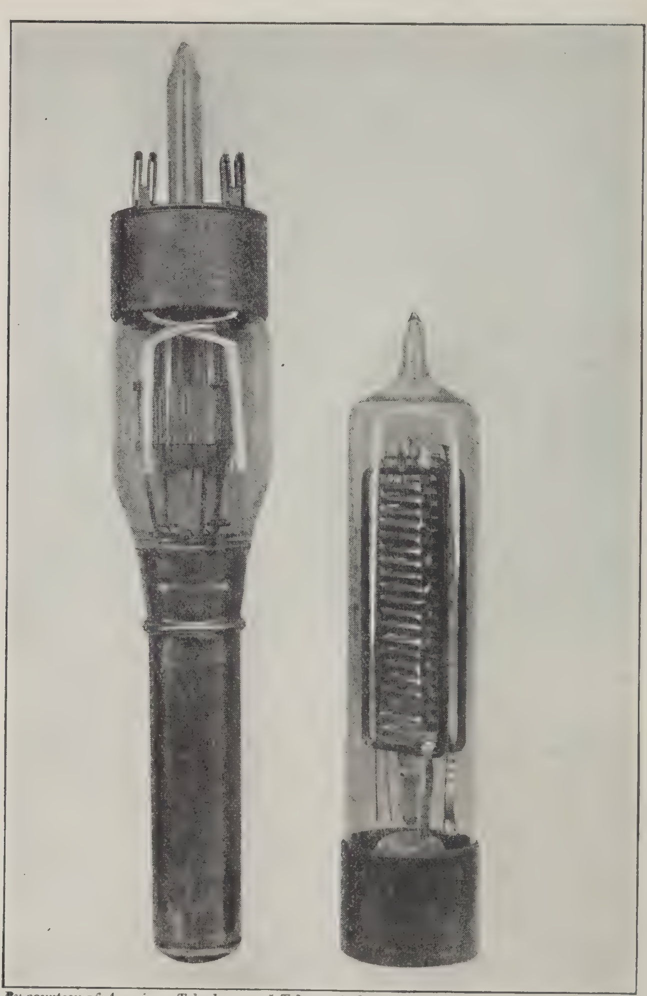
Vacuum tube sending sets can be used to send messages in dots and dashes as well as for the radio telephone. The radio telephone, however, has grown to be more important than the radio telegraph.



*By courtesy of National Broadcasting Company*

FIG. 114. A PORTION OF THE CONTROL BOARD OF A BROADCASTING STATION

It is impossible in a book of this kind to tell of the newest improvements in radio sets. While the book was in press improvements were being made. What was new when the book was written is no longer new when the book leaves the press. In almost every newspaper you pick up you see such headlines as "Better Type of Tube Made," "New Type of Aërial Tried Out," "Experiments With Short Waves Being Carried On," or "New Connections in Receiving Set Found Satisfactory." Figure 115 gives some



*By courtesy of American Telephone and Telegraph Company*

FIG. 115. TRANSATLANTIC VACUUM TUBE OF 1927 (ON THE LEFT) COMPARED WITH THAT OF 1915

idea of the type of improvements being made in vacuum tubes. The tube on the right is one of the tubes used in 1915 by the American Telephone and Telegraph Company in sending a spoken message across the Atlantic. Five hundred of these tubes were used to make it possible to send a message such a long distance. The tube on the left is a tube of the kind now used by the American Telephone and Telegraph Company in sending messages across the Atlantic. Only twenty-three of these tubes are needed. One of these newer tubes is four hundred times as powerful as the older tube.

In the newspapers to-day more space is given to radio than to any other use of electricity. When the telephone was first invented, it was considered an interesting amusement device. As you have been told, entertainments were given in which music played in one town was heard by an audience in a neighboring town. Soon, however, the usefulness of the telephone in business far outweighed its importance as an amusement device. Radio is now in the stage where its chief use is as an amusement device. Of course, the importance of the telephone as an amusement device never approached the importance of the radio as an amusement device to-day. Now there are about six hundred broadcasting stations in the United States which broadcast programs regularly.

Will radio reach the stage when it is more used for other things than for entertainment? It is certainly very helpful in other ways. The fact that regular trans-Atlantic radio telephone service has been established is enough to show that radio is not a mere plaything. In times of floods and such disasters the radio is, in many cases, the only way of sending a message concerning the disaster. Telegraph and telephone lines are down; autos and trains can't travel; but the radio works as well as ever.

When an explorer leaves civilization to find out about new corners of the earth, he can't set up telephone or telegraph lines as he goes along. His only way of keeping in touch with civilization is by radio. When Amundsen went to the South Pole, there were weeks when no news of the expedition could be had. He couldn't announce to the world that he had reached the South Pole for days after he had done so. When he flew in the dirigible Norge over the North Pole, he was able, by means of the radio set he carried with him, to send back word immediately that he had reached the pole in safety.

Perhaps the most spectacular use of radio is in rescuing ships at sea. An SOS call by wireless brings to a sinking ship help from all the ships near at hand. In the early history of radio, no story was more thrilling than the story of how Jack Binns, the wireless operator on board the Republic, stood by his post and succeeded in getting help when the ship was sinking, and the lives of about two thousand people were in danger. Now all ships carrying fifty or more persons are required by international law to carry radio equipment and competent operators. Because of radio, ocean travel has become much less dangerous than it used to be; an ocean voyage is even safer than a trip on land.

Another important use of radio is in the broadcasting of lectures. Many universities and colleges broadcast lectures regularly. Some universities are even planning to give courses by radio.

Will the radio do away with the ordinary telephone, telegraph, and cable? It has already lessened their importance to some extent. Radio, however, is not entirely dependable. At times the electricity in the atmosphere, the so-called "static," interferes greatly with receiving messages. When Amundsen was flying south from the North Pole toward Nome, Alaska, he was shut off from communication by a "wall of static." Street cars, arc lights, motion-picture machines, vacuum cleaners, electric heating pads, and electric traffic signs interfere with receiving radio messages, too. Perhaps ways will be found of getting rid of such interference.

Will radio do away with newspapers? Probably not. If some one at a broadcasting station were to read aloud all the news in one of the big daily papers, it would take from eight to ten hours, and the person who wished to hear all the news would have to be listening all that time.

When you see how much has been accomplished with radio in the past thirty years, you realize how foolish it would be to try to predict how much farther it will be developed. Hammond, an American inventor, has been able to control boats, airplanes, and torpedoes from a distance by means of radio. Such a use of radio might become very important. Television, "seeing far away," is still in the experimental stage, but already remarkable results have been obtained. We may look forward to seeing interesting events by radio in addition to hearing about them as we do now.

One question which many people have puzzled about and which has found its way into the headlines of the newspapers from time to time is, Will it ever be possible to get messages from Mars? If a scientist should say that he fully believed that we shall in time be able to get messages from Mars and send messages to Mars, it would mean that he believed three things: that there are people on Mars; that radio is developed there as far or farther than it is on the earth; and that radio waves can travel the millions of miles through space between the earth and Mars.

As a matter of fact, most scientists believe that conditions on Mars are such that no living beings such as we are could possibly live there. Even the few scientists who believe that Mars is inhabited have no reason for thinking that the inhabitants would know anything about radio. Some scientists, moreover, believe that the waves from the broadcasting stations here never get far away from the earth. If that is true, then communicating with Mars by radio is impossible even if there are people on Mars. But what of that when we think of the wonderful things radio can do here on the earth?

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